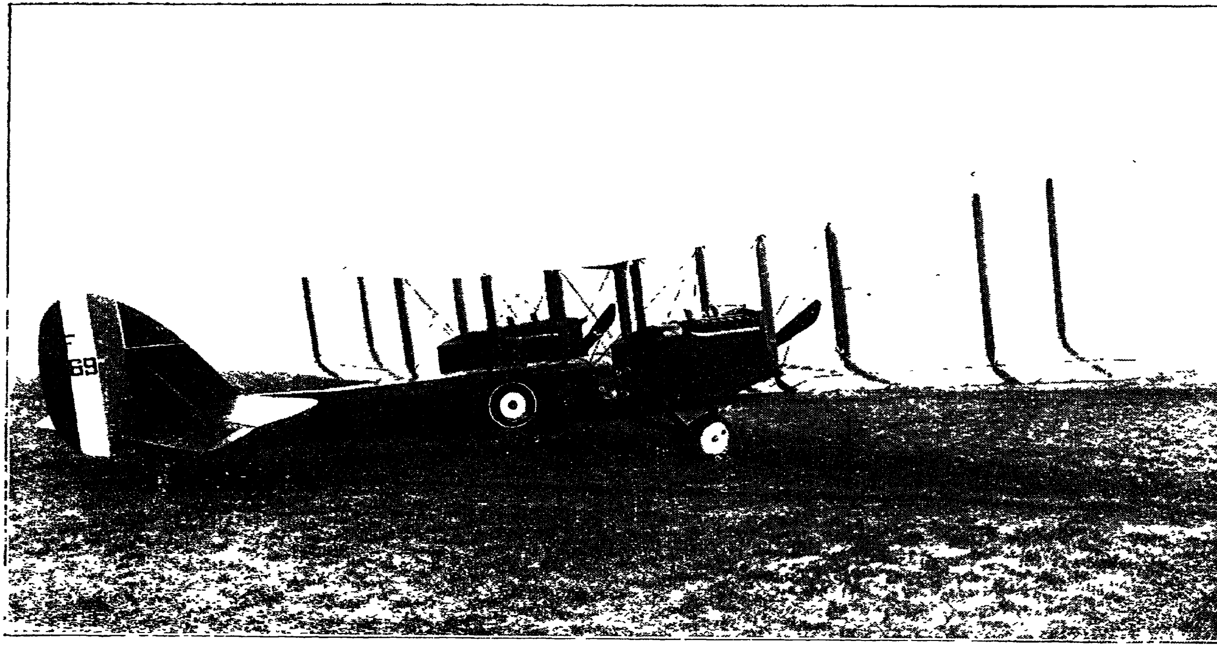
THE WAY TO FLY



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The famous twin-engined D. H. 10A (Aircraft Manufacturing Co.). This aeroplane can climb as high and fly as fast as most single-seater fighting scouts, and needs no escort.

Frontispiece

THE WAY TO FLY

AN INTRODUCTION TO FLIGHT FOR BEGINNERS

BY

"AVION"

AUTHOR OF
"AEROPLANES AND AERO ENGINES"

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THE WAY TO FLY

CHAPTER I

INTRODUCTION

FLYING cannot be learnt from books. This manual is intended for the preliminary study of readers who hope to graduate as pilots in the future, and for those who desire to know something about flying, even though they cherish no intention of tasting its experiences.

In the first place it must be clearly understood that the war has temporarily barred flight to a great many people who will fly in safety and with enjoyment when normal conditions return. Every war pilot must be sufficiently robust to stand prolonged flights at altitudes of at least 15,000 ft. and in intense cold. In peace time a pilot who flies for pleasure need never exceed a height of 3,000 ft. and may remain on the ground when the air is cold, whilst professional commercial pilots will certainly not be compelled to climb above 10,000 ft., and will be very fully protected from the weather. Again, the war pilot requires magnificent sight; it is necessary that he should excel in the most difficult form of snapshooting imaginable, and, further, that he should possess the eye of a hawk for sighting possible victims or assailants at any angle at great distances, and in spite of considerable distractions and a very limited field of view. In peace flying the demands upon a pilot's sight are much less exacting, and many good flying men of the future will wear spectacles in spite of the difficulties imposed by rain and clouds. On the other hand, nobody should learn to fly, or even travel in an aeroplane as a passenger, without first consulting a doctor. For leisurely flying under peace conditions almost any

physique will suffice; but it is nevertheless true that a weak heart, any tendency to giddiness, or a liability to fits of any kind are absolute and permanent disqualifications for flight. Apart from these three embargoes, most men up to middle age and quite a large proportion of women below thirty years of age may safely fly either as passengers or as pilots, so far as the physical factor is concerned.

Temperament is at least as important as physique in this connection—probably more so. Flying demands three qualities above all others in its disciples—a knack of lightning decision, a cool head, and the accurate response of the muscles to the decisions of the brain which controls them. Training can undoubtedly develop these qualities in persons who on first trial seem to be devoid of them. In the hurry of war there is no time to waste months in educating a man who thinks slowly, easily becomes flustered, and is clumsy in his movements. In peace time training will only be limited by the amount of money which the pupil is prepared to spend. A small percentage of people, who are naturally slow-witted and clumsy, will baffle the most patient instructor; but when time ceases to be so important, almost anybody who can pass a lenient medical examination can be trained into at any rate a mediocre pilot. The born pilot, male or female, will still be the quick-witted, light-handed person with steady nerves. It is a matter of experience that sport tends to develop latent gifts of the required kind. Motoring in all its forms, riding and driving horses, sailing a boat, and similar pastimes are excellent schools for pilots. The boy or girl who is a failure at games will not often learn to fly really well.

Thus, the youthful training of the intending pilot should certainly include those games which call for instant decision in the face of risks—even if the risk be nothing more serious than the loss of a game, although genuine physical risk is preferable; considerable muscular dexterity, a connection in which such gentle games as billiards and croquet and ping-pong are not to be despised, absurd as the connection might appear at first sight; and—above all—the conquest of "nerves," if the would-be aviator is at all imaginative.

Simultaneously, since flight is a mechanical form of locomotion, engineering studies should not be neglected. A mastery of the petrol engine is invaluable. During the war some of the best instructors used to remark that the less a

pilot knew about his engine, the better; but in peace time engine failure will seldom involve any risk, and sound knowledge of the power unit will be indispensable. The theory of flight and the construction of aeroplanes should also be mastered. A simple introduction to all these topics is provided in *Aeroplanes and Aero Engines* (price 2s. 6d. from the publishers of this volume). To sum up the qualifications thus briefly outlined, a peace-time instructor would probably have high hopes of a pupil who was a daring motor cyclist, had won two or three track races and hill climbs, could take his machine to pieces and make it run better than ever, and who was in the habit of constructing model aeroplanes which would fly. At the same time a boy (or even a girl) who appeared at a flying school with none of these qualifications would generally train into an average pilot, and in a certain percentage of cases would develop into a star pilot.

Writing before the war has ended, it is impossible to dogmatise about the flying schools of the future. Since 1914 instruction has been practically a monopoly of the military authorities. Aviation has made an unparalleled appeal to the imagination of our youth, and it will unquestionably offer a very fascinating career to a chosen minority after the war, though it will be less remunerative to pilots than is generally supposed—after a certain lapse of time the pilot of an aeroplane or airship will approximately correspond to the driver of a locomotive or the steersman of a ship. During the period of transition from war flying to peace flying, flying schools will spring up like mushrooms, and some of them will be inefficient, others perhaps mere catchpenny swindles. Considerable caution will be advisable in paying the somewhat heavy fees which even an honest and well-administered school must always demand for an adequate training. During a possible interval of unscrupulous advertising, expert advice should be sought before a choice is made; after a few years some governing body will assume control, and a system of Government permits will probably have to be instituted. In the immediate future aspirants can hardly be too cautious.

It is impossible to estimate the scale of fees for such tuition. In 1914 the sum of £100 was commonly paid for a very superficial course of training, and aspirants may fear that thrice this sum will be the post-war standard, considering the

universal rise in prices. Such fears are probably unnecessary. The quality of the school machines and the system of instruction have been perfected by four miraculous years of compressed experience. The pupil of the future will master the handling of a machine in a comparatively short time, and will cost the school next to nothing in the way of repairs. On the other hand, the best schools will be organised to give their pupils a thorough training in the general mechanics of flight, including the theory of the aeroplane and its engine, and the general maintenance of both. The exact scope of the curriculum will doubtless depend on the standard imposed by law or by a governing body for the pilot's brevet or diploma. It is very certain that a minimum standard of proficiency and knowledge will be demanded by statute from anybody who aspires to fly across country on projectiles weighing upwards of a ton and capable of at least seventy-five miles an hour, features which imply grave potential risks to the lives and property of the public. As soon as legal tests are imposed, the flying schools will accommodate their "courses" to the recognised standard, and fees will tend to settle down. Until that happens, the advice of an expert should be sought and followed.

For allied reasons it is as yet impossible to estimate what flying will cost the rich man who indulges in it as a hobby, or as a successor to the motor-car and steamship in fast long-distance travel. It is only possible to say that a long journey in a public service aeroplane will certainly compare very favourably in cost with any rival form of transport, for the simple reason that board and lodging are the most costly items in trans-continental or trans-oceanic journeys by older methods of travel, and that flying at upwards of 100 miles an hour practically eliminates these expenses. On the other hand, the personal ownership of a private aeroplane will always be extremely costly. An aeroplane requires a good sized piece of ground for starting and alighting purposes. It is less easily and cheaply housed than a motor-car. It demands skilled attention from a squad of highly trained mechanics after every flight. Finally, it is practically unsaleable second-hand, and depreciates in value with extraordinary rapidity. Some of these factors will gradually undergo modifications. In the course of time, every large town will come to possess its public aerodrome, and country clubs will perhaps cater

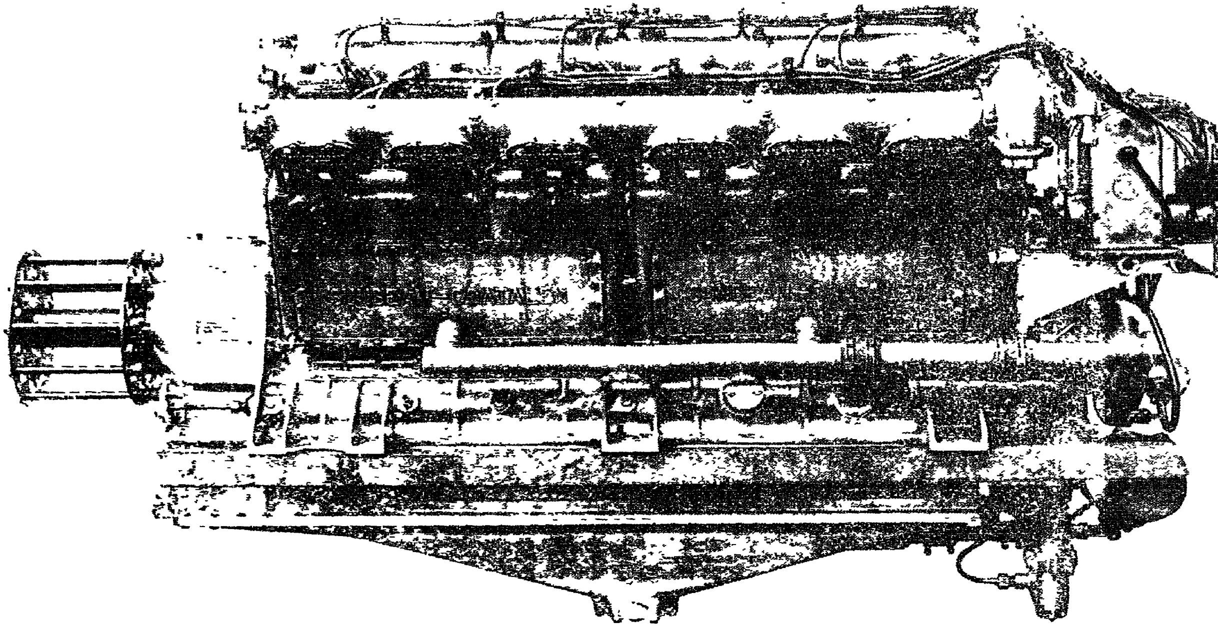
for the more exclusive type of owner. The introduction of all-metal aeroplanes will render the daily "rigging" of the machine quite unnecessary, and endue it with a much longer working life. Aero engines will lose their sensitiveness, and may ultimately be satisfied with an overhaul every autumn, after the manner of a motor-car engine. But for some years to come the owner of a private aeroplane should be prepared to write off the whole of its first cost as a dead loss, and in addition to spend quite an appreciable weekly sum upon rent and maintenance. To name a single concrete example of the probable expenses, a slow single-seated machine, with a 50 h.p. engine will probably cost its owner £1 in fuel for every hour of flight.

This forecast suggests that in the next generation few people will enjoy much experience of flight except as soldiers, professional pilots, ticket-owning passengers, or occasional joy-riders. Military aviation will unquestionably be the most attractive branch of the service, and as boys must always make the best scout pilots, junior commissions will always be obtainable by picked candidates. It remains to be seen what prospects the Royal Air Force will offer as a life career under peace conditions. There will be a permanent influx of eighteen-year old boys at the bottom, for very few of whom space will be found as age impairs their value as potential fighting pilots. It hardly seems probable that every peace-time second lieutenant R.A.F. can automatically rise to captain or major, as is the case in the infantry and other corps. More probably, the peace-time establishment will be incomplete so far as young pilots are concerned, but civilian pilots will be given commissions in the reserve until they are, say, 25 years of age, and would join their squadrons in the event of mobilisation: the problem is extremely intricate, and at the moment it can only be said that the positions of infantry and Air Force subalterns on the peace establishment will not necessarily be parallel.

It is equally difficult to estimate the prospects of a professional civilian pilot. At the moment they could hardly be worse, for the supply will vastly exceed the demand until the bulk of the army pilots have drifted into other professions or become superannuated. When the temporary excess of pilots which peace will create has been exhausted, flying as a career will depend on a variety of factors. There

will always be room at the top. A pilot of unusual skill, who is a trained engineer, will always be sure of well-paid employment with manufacturing firms. The pilot whose sole qualifications are average ability in handling a machine and a fair knowledge of navigation, may well prove a drug on the market. The profession will make a keen appeal to adventurous boys, and will always be overcrowded. The number of openings will depend on the rate at which commercial flight is developed. The social position of the commercial pilot and his salary will perhaps hinge largely on the size of the aeroplane of to-morrow. So long as the bulk of aerial traffic is conducted by small planes carrying a very few passengers, the pilot will shoulder a heavy responsibility, and will be esteemed accordingly. If the giant aeroplane is developed, and trans-oceanic liners, conveying dozens or hundreds of passengers, come into vogue, the aerial liner of the future will be under the charge of a captain, and the actual pilot will be little more than a chauffeur. The captain may quite probably be an ex-pilot, but in no case will the commercial pilot enjoy the prestige or the prospects which justifiably attached to the fighting pilot in the Great War. It is also clear that the life of a commercial pilot will attract the best youth of the country, irrespective of birth or wealth, and that flight will not be a "caste" or "class" profession, as was partially the case during the war. Snobbishness has almost died out since 1914, but it is quite capable of resurrection, and it flourishes as strongly in a democratic soil as in the ancient loam of feudalism.

Considerations of danger are deferred to the end of this chapter for logical reasons. Paradoxical as the statement sounds, flight is already quite extraordinarily safe. Aeroplanes are in their infancy. Aero engines are so new that in the year 1914 there were perhaps two British patterns which were airworthy, and neither of these long survived the stress of war. The air is still a comparatively unknown medium to us, as the sea was to the Jew of old. Our brief and paltry experience of flight has chiefly been garnered under the artificial conditions and exaggerated dangers of war. We have been compelled to prefer power and lightness to reliability in our engines; speed and climb to stability in our planes; economy of time to thoroughness in our training; dash and recklessness to a cool wariness in our pilots. In spite of these abnormal



250 H.P. SUNBEAM-COATELEN ENGINE.
"Maori" pattern. Vee type. Twelve cylinders.

To face page 17.

conditions the tale of accidents bears an astonishingly low proportion to the number of hours flown; the actual figures may leak out in the near future. Above all, as soon as a pilot becomes expert, he is sent out to France where he presently falls a victim to the perils, not of flight, but of war; so that our statistics since 1914 are based upon a perpetual succession of novices flying under conditions of artificial peril. The conditions are much the same as if our roads were perpetually full of eighteen-year-old boys driving high-powered cars and motor-cycles for the first time. Nevertheless, though practically every resident in England has seen hundreds of aeroplanes aloft, very few have ever witnessed an accident, even afar off.

To phrase the same fact in a more technical manner, an aeroplane is generally considerably safer than a ship or a train or a motor-car, provided it is at a height of 1000 feet or more. It is constructed with such a great margin of strength—usually six times more than is necessary in theory—that it is practically impossible for its structure to fracture or buckle in mid-air. In the event of such minor mishaps as an engine stoppage, the machine can still be glided to earth with absolute safety, and the only doubtful question is whether or not a safe landing ground can be found within reach of the glide. At a height of 1000 feet a pilot can select a landing ground within an area of several square miles without using his engine at all; so that a safe descent after a breakdown in the air simply depends upon the height of the machine at the time. In other words, aerial breakdowns are only dangerous at low altitudes. The peace-time pilot who flies steadily and cautiously until he is 1000 feet up, and similarly observes care in the last 1000 feet of every descent, is not at all likely to meet with accidents. In sober fact, aeroplanes are even safer than the foregoing statements imply. Designers fully understand how to make aeroplanes which are "automatically stable"; prior to the war, a B.E. 2 C. Army machine was flown twenty miles without its controls being touched by the pilot, and such a machine can actually land itself. For certain reasons such a high degree of stability is not always desirable in a war plane; but when peace flying develops, safety will become a more important consideration.

To summarise this introduction, almost any ordinarily healthy person may learn to fly. The cost of flight as a hobby

must remain prohibitive for the ordinary citizen. The prospects of flight as a profession are extremely dubious. In any case, as complete a technical training as possible is desirable. The dangers of the new locomotion are vastly exaggerated in the popular imagination.

CHAPTER II

WORK ON THE GROUND

The impatient student naturally wishes to "go up" at the first opportunity; and he will be wise to remember that even under the stress of war a Royal Air Force cadet often spent three months of concentrated study on the ground before he was permitted to make his first flight on a "dual control" school machine with an instructor. It is true that the war pilot has to master various military studies which do not concern the peace pilot; on the other hand, the peace pilot will be expected to master various professional matters in which a mere smattering sufficed for the flying officer. The period required for preliminary studies is likely to lengthen rather than diminish; for a student who desires a thorough grounding the following subjects are essential:

1. A course in general engineering.
2. A course in the theory of flight.
3. At least a year in an aeroplane factory.
4. At least a year in an aircraft engine factory.
5. As much practical work in an aerodrome as possible.

The above stipulations represent the minimum which will be expected of any pilot who hopes for a remunerative position under peace conditions. Such an education will obviously be costly. The boy who has no wealthy parent or personal capital behind him must either approach the pilot's brevet through the Royal Air Force, or try to find an inexpensive back door into the desired career through employment as a mechanic in an engine factory or at an aerodrome. The indicated education may possibly be obtained at comparatively small expense by working through the engine and aeroplane shops as a paid fitter, and studying the theoretic aspects at a technical school. Only a few exceptionally fortunate or capable individuals will reach the goal by this route. Labour

is now classified and sub-divided so that an ordinary factory hand can hardly hope to master a given trade from A to Z; and a series of ingenious transfers, e.g. from carpenter to rigger, and from rigger to erector, would take years, by which time the pupil's age would have become a handicap in flight. Where economy is necessary, the Royal Air Force is almost the only sure entrance to a pilot's career; and it remains to be seen whether privates and non-commissioned officers will be given their "wings" on any large scale after the war.

Where money is of small account, the aspirant will do well to work as an ordinary mechanic in both aeroplane and engine shops. The premium apprentice usually remains an amateur to the end of his days. Influence or money should be employed for no other purpose than to shorten the time under which comprehensive factory experience under normal labour conditions can be gained. The student should master as much theory as possible before he commences practical work, so that he may assimilate in a minimum time what each job should teach him.

It must be clearly understood that the post-war pilot will be a man of considerable technical knowledge. During the war some of our finest pilots obstinately disdained the mechanical aspects, and served the country well merely because they handled their planes and guns magnificently. The post-war pilot will be, above all things, an engineer. Ignorant men, who can handle planes superbly, will be as common as blackberries, and as cheap. In the matter of salary they will be in much the same position as a golfer with a handicap of 18 who desires a berth as professional to a club. Parents should gently discourage the son who wants to be a pilot, but who dislikes school and shows no evidence of brains above the average calibre. Such a lad may train into a mechanic, worthy of a mechanic's wage; but he will never command either the prestige or the pay attached to the position of a R.A.F. subaltern in war time.

In the compass of this manual it is only possible to outline the kind of practical knowledge essential for everybody connected with flight. In Chapter III the handling of engines in aerodromes is described, and in Chapter IV the maintenance of the aeroplane itself is dealt with.

CHAPTER III

ENGINE ROUTINE

A WELL-EQUIPPED aerodrome is provided with a few spare engines, over and above the number required for the daily use of the fighting squadron or mail service based upon the aerodrome, so that a certain percentage of the engines are always undergoing overhaul and repair without interfering with flight. The engines in the shops at any date will consist partly of engines damaged in a "crash" or by an internal breakdown during flight, and partly of engines which are in running condition, but have flown for so many hours that an overhaul has become a wise precaution. Such preventive overhauls are given to all aero engines at intervals which vary with the type of engine and with its maker's reputation. Thus a rotary engine or a stationary air-cooled engine will be taken out of the aeroplane at shorter intervals than a water-cooled engine, because rotary engines get very dirty in use, and air-cooled engines are more liable to approach a danger point in temperature. Similarly, every experienced mechanic knows that a first-class water-cooled engine will run longer periods between overhauls than a similar engine built by a firm of less reputation. Again, a very light racing or "hot-stuff" engine of the high efficiency type will always be nursed and treated with a certain amount of suspicion, whilst a "motor-bus" type of engine, built for sedate heavy duty, may be trusted up to 100 hours of flight. Broadly speaking, an ordinarily good engine will receive what is called a "top overhaul" after 40–50 hours of flight, i.e. its cylinders and valves will be inspected, cleaned, and adjusted, and after 80–100 hours the entire engine will be stripped right down. Since engines tend to become more and more cumbrous, and hence more inaccessible after installation in an aeroplane, the "top overhaul" is becoming almost obsolete except where rotary or radial engines are concerned; if the engine

has to be taken out of the fuselage for its cylinders, valves, etc. to receive attention, it pays to strip the engine completely when it is removed from its bearers.

The engine being the most costly item of an aeroplane, every effort will be made to keep as many engines continuously fit for service as possible. For this reason the mechanics will be organised in day and night shifts; and until night flying becomes all but universal, the night shift will usually be the bigger squad. At an aerodrome where the flying is practically confined to daylight, the mechanics will be divided into (*a*) the machine shop staff, who undertake heavy repair jobs, lasting for several days or even weeks; (*b*) a small squad of "general utility" day workers; (*c*) a large night squad, who will come on duty when the aeroplanes return from their day's work, and who will put all the serviceable engines in proper trim for the next day's flying. The "general utility" men will be conversant with the whole of the engines and their fittings, will undertake small emergency jobs occurring during each day's flying, and will fill up their time by assisting with the lengthier repair jobs. The *c* or night squad will be subdivided according to their respective duties. The same men will always dismount the engines from the fuselages. The lighter duties will be entrusted to particular individuals: thus, the replenishment of the fuel, oil, and water tanks, attending to the ignition, carburettors, instruments, lubrications, etc., should always be entrusted to a particular workman or, if necessary, set or gang of workmen. Another small gang will take over the engine from the squad who dismount it from the nacelle or fuselage, and will proceed to take it to pieces. The various jobs connected with the re-erection of the engine will similarly be repeatedly performed by the same man: thus, one man will always time the valves, a second will reset the ignition, a third will be responsible for grinding the valves, a fourth for inspecting the bearings, and so on. Only under a specialist system can all these skilled jobs be performed with the maximum efficiency in the minimum time.

Secondly, as an engine failure cripples the aeroplane for the time being, and may possibly endanger the lives of its occupants, a severe system of checks must always be organised. It must never be taken for granted that the best hand has done his work perfectly. Each hand must be trained to

use extreme care, and to check his own work when complete, attaching his signature to a label or job card. The work should then be checked, and the label countersigned by his immediate superior. The engine foreman will exercise all possible supervision throughout. When re-erection in the fuselage is complete, the engine will be thoroughly tested over its full range of speed and power. Before the machine is wheeled out for a flight, the whole of the job should undergo ocular inspection once more, and a further running test should be made well in advance of the pilot's arrival. The pilot himself will make a final running test before he " taxies " out to start a flight.

When the machine lands, the pilot will make a written report of the engine to the foreman of the engine squad. Inspections and adjustments will be made in accordance with a set of standard orders or requirements, based upon prolonged experience of the type of engine in use. A short running test will conclude the work, after which the machine will be housed for the night. Next morning the whole series of tests and inspections will recommence. These proceedings may savour of fussiness to men accustomed to the happy-go-lucky methods of a small provincial garage ; but there is a colossal difference between a roadside stop with a motor-bicycle and an engine stoppage when an aeroplane is just getting off the ground. With aircraft engines *nothing must be taken for granted.* It is wise to suspect and supervise such simple routine work as the filling of fuel, oil, and water tanks, or the storage and cleaning of oil funnels, to smell every can from which fuel is taken, to conduct precise daily tests of every accumulator, and generally to eliminate every conceivable cause of trouble.

In summing up the general character of the various jobs which centre round the engine, it is simplest to commence at the moment when the aeroplane lands after its last flight of the day. Let us suppose that the weather is sufficiently fine for the work to be done just outside the entrance of the hangar, to which the pilot has taxied the machine before climbing out of the cockpit. There is ample daylight remaining, and the report of the flight suggests that the engine has pulled well throughout, and requires nothing more than a general look over.

A small gang of men begin to get busy about the machine.

Each man is tackling an accustomed job and is quick and smart. The foreman knows from long experience at what moment he must check the doings of his underlings, and in a surprisingly short time the engine is ready for the final running test before the machine is wheeled inside, and the hangar closed up for the night. Summary :—

AFTER A FLIGHT

1. Fuel, oil, and water tanks refilled. The consumption of the last flight can be gauged by the quantities required for replenishment, all of which are recorded. All piping and connections are inspected for general condition and for leaks of liquid or air.

2. Ignition. The fitter in charge will probably remove one set of sparking plugs and insert a spare set, which have been cleaned and tested (the other set—there are two plugs per cylinder—will be changed after the next flight). All the sparking plug cables will be inspected for tightness of terminal connections, absence of cuts or chafing, damage to insulation through heat or oil, etc. If magnetos are used, the fitter will open up and wipe out the distributor, inspect the contact-breaker to see that the lever arm works freely, and that the platinum points are clean and show the correct gap, and note that the two magnetos "synchronise," or spark at exactly the same moment for each cylinder. If accumulator ignition is employed, a freshly charged battery will be wired up, and all necessary tests and inspections made. In either case, the switch, switch wiring, and ignition control levers and connections will be overhauled.

3. Carburettors. This item does not require much attention, except at long intervals. If the pilot's report is favourable, the fitter in charge will probably content himself with seeing that all the control connections are in order, and opening up the float chamber. If he should find more than a few specks of dirt, he will dismount and cleanse the entire carburettor. Otherwise, he will merely shake the float to make sure it is not punctured and test the flow of petrol from the supply pipe.

4. Propeller. A skilled propeller hand will inspect the propeller, and if necessary fit a new one (rain, snow, and hail soon render a propeller unserviceable, whilst any heating of

the propeller boss causes the glued joints in the blade to gape). The locking of the nuts on the hub bolts and of the securing device of the hub will also be tested.

5. The petrol and oil filters will be taken out and cleansed.

6. The stuffing gland of the water pump will be inspected, and if necessary repacked. The water pump will be greased.

7. If wind-driven pumps are used for feeding petrol from the tank to the carburettor, they will be inspected.

8. Valves. A mechanic will inspect all the valves of the engine, and test their tappet clearances with a feeler gauge. The pilot may have reported that one or more valves (probably exhausts) are inclined to stick, in which case the foreman may be called in to decide whether the faulty cylinder must be dismantled, a job which may entail the removal of the engine from the plane. The valve can probably be freed by taking off the spring (after putting the piston at the top of its stroke), lubricating the valve guide with paraffin, and working the valve up and down by hand.

9. All nuts will be inspected, especially those by which the engine is secured to its bearers in the fuselage; their locking devices will receive special attention.

10. The oil tank will probably be drained, as any remaining lubricant will have lost its qualities by being circulated through the engine.

11. Possibly the crank-shaft will be turned round by means of the propeller, both against full compression and with the compression released by the removal of all the sparking plugs. The former test will show whether each cylinder offers the normal resistance, and the latter will indicate whether all the bearings are free.

12. Finally, a running test will be made with the wheels of the under-carriage chocked and the tail held down. The usual routine of question and answer will be observed in starting up, as everybody concerned knows that unwary mechanics are occasionally killed by the propeller. The tester will first see that the engine starts easily, and that the gauges show their proper readings, indicating that the oil and petrol systems are working properly. Then he will test the engine over the whole range of its speed on each ignition separately. When he is satisfied, the machine will be wheeled inside. Heating apparatus may perhaps be arranged to ensure a prompt start next morning, and the hangar will be closed up.

BEFORE A FLIGHT

(1) *In the Hangar*

Early next morning a squad of men will to all intents and purposes repeat the above inspections either inside the hangar or just outside it. The morning inspection will be a little less penetrating than that described above, and will be of a more superficial and external character. The details will vary according to the ideas of the management. It is hardly likely that the sparking plugs will be inspected a second time, or that the lid of the float chamber will be again removed. But in all probability the contents of all the tanks will be verified, all joints and connections will be inspected, etc. A preliminary running test is certain to be made before the pilot is expected, both as a check on the previous night's work and also to warm up the lubrication system. Where a martinet is in charge, or at a first-class flying school, the operations of the foregoing evening may be repeated from start to finish, very possibly by an entirely different squad of mechanics; it is obviously a serious thing for a flying school to have a pilot killed through his engine failing soon after he has "taken off," and some proprietors insist on a wise, if wearisome, duplication of inspections and tests.

Under all conceivable systems of aerodrome management, the main difference between the evening and morning work lies in the need for warming up the lubrication system after a cold night in a hangar devoid of heating. This job needs care, and may occupy as long as half an hour in the case of a long-distance machine. Imagine, for example, that the manufacturers of the engine specify that the lubricating oil shall circulate through the engine at a pressure of 25 lbs. per square inch. On starting up a cold engine on a cold morning, the gauge may immediately register 50 lbs. This implies that the congealed oil is building up heavy resistance in the small pipes near the pump and that parts remote from the pump are not receiving any supply of oil. The engine must be run as slowly as possible until the gauge registers 25 lb. only. At low engine speeds the bearings are not heavily taxed, and will subsist on the oil remaining in them from the last run. If the oiling system is on the "dry sump" principle, in which the contents of a tank are forced through the engine and

pumped back into the tank, a long period will be necessary to warm up ten or twelve gallons of oil. In this case the engine should be run for three minutes, then stopped for three minutes during which the cylinder heat can radiate through the engine, started up and run for three minutes, and so on. Not until the oil leads most remote from the pump feel warm to the hand and the gauge registers the correct pressure steadily, can the engine safely be accelerated.

If the engine is of the rotary type, the oil is not circulated, but is blown out of the exhaust after passing into the engine. In this case it is only necessary to see that oil is flowing freely down the supply pipe from the tank ; this is easily done by uncoupling the union momentarily, using the tap to prevent waste of oil.

Some modern machines are equipped with a device to correct the petrol and air mixture for great heights. There are a variety of such devices, most of which produce a weak mixture if they are operated at ground level. The greatest caution is required in testing them on the aerodrome, since a weak mixture generates intense heat, is apt to burn the valves, and may fire back down the inlet pipe and cause a fire. Tests should therefore be left to experts.

(2) *Pilot's Final Test*

The final inspections, performed by the pilot himself, will vary according to the trust he reposes in his mechanics, his own temperament, and the discipline of the aerodrome ; but it is unquestionably best that he should personally repeat all the previous checks. In any case he should check the contents of the fuel, oil, and water tanks.

STARTING THE ENGINE

There are three main systems of starting the engine. Either a mechanic stands facing the nose of the machine and uses the propeller as a starting handle ; or else an electric dynamo or other mechanical means is used to revolve the engine ; or the pilot turns the handle of a " booster " magneto, which is not geared to the engine, but supplies current to the distributors of the service magnetos and produces a late-timed spark at the plug of whichever cylinder is on the firing stroke.

In all three cases the cylinders are first "doped" or primed with petrol, the doping instrument being either a hand squirt employed through an open valve, or a special apparatus constructed as part of the engine. If no mechanical starter is fitted, a mechanic will distribute the "dope," or cause mixture to be sucked into the cylinders by pulling the propeller round. Whenever mechanics are required to stand in front of the machine a stringent system of question and answer must be employed between pilot and mechanic, otherwise one of the men will sooner or later be killed by the propeller. This danger is extremely real, and its avoidance must never be left to chance.

Before entering the cockpit the pilot should see that several men are waiting to hold the tail down and prevent the aeroplane tilting over on to its nose when he tests the engine at its full speed, and that chocks are in position before the wheels to prevent the machine from moving across the aerodrome when the engine starts. Ropes attached to these chocks are held by men standing clear of the aeroplane at either side, ready to twitch the chocks away when the pilot signals that he is ready to take off.

The pilot may now climb on board, see that he has everything required for his flight—maps, gloves, goggles, etc.—and make himself comfortable in his seat. After testing the aeroplane controls (see page 42) he prepares to start the engine. If he has a mechanical starter he does this single-handed. He turns on the petrol, puts the throttle in the slow running position, possibly closes the air intake, and then operates the starter to charge the cylinders with gas. After the engine has turned two or three times, he switches on and the engine starts. If he requires the assistance of a mechanic the routine will be somewhat as follows, all remarks being repeated by both men to avoid blunders:

Mechanic: "Switch off?"

Pilot (after verifying switch position): "Switch off."

Mechanic: "Petrol on?"

Pilot (turns on petrol): "Petrol on."

(Mechanic then turns the propeller round as sharply as possible several times, to suck in gas into the cylinders. Then he stands back well clear of the propeller and shouts "All clear.")

Pilot replies "All clear," and proceeds to spin the handle

of the booster magneto. If the engine does not start the pilot calls out "Switch off," the mechanic repeats, and the pilot gives orders to "Suck in," i.e. to turn the propeller again and recharge the cylinders.

If no hand-starter magneto is fitted, the mechanic will actually set the engine in motion by "swinging the propeller." In this case the drill must be very precisely adhered to, and the words "Contact?" "Contact" are used instead of "Switch on?" which might be confused with "Switch off." Furthermore, the mechanic must not wear loose clothing or flapping sleeves, and should insist on the aeroplane being placed so that he has a patch of firm dry turf to stand on. The safest method is for the mechanic to pull down the propeller with one hand, whilst another mechanic or string of two or three mechanics link up to his free hand, so as to pull him clear when the engine starts. No mechanic should be asked to swing a propeller more than three or four times without a good rest; the effort is extremely exhausting, and a tired man is likely to do something foolish.

FINAL ENGINE TESTS

When the engine starts, all hands clear away from the front of the machine, whilst the men on the chockropes and at the tail watch the pilot closely. He first of all inspects all the instruments which concern the engine, noting that the oil is circulating freely at the correct pressure and that the petrol is feeding properly. As soon as the oiling is satisfactory, he proceeds to open the throttle gradually and ascertain whether the engine reaches its full revolutions per minute ("r.p.m.") on each of the two ignitions separately. He listens to the beat of the engine and satisfies himself that its running is normal. In all probability he accelerates the engine and slows it down again several times over, to make sure that it will not choke in the air. If any compensating device for high altitude is fitted, he tests it, but the test will be extremely brief, as such devices are apt to burn the valves or even cause a fire if prolonged tests are made at ground level. When he is perfectly satisfied with everything he gives the mechanics the signal to be on the alert; this signal varies, but may take the form of merely glancing round to see that all the men are watching him closely.

The engine is now running smoothly, well throttled down. The pilot glances round at the men, and then holds up his hand smartly. The men with the ropes jerk the chocks clear of the wheels. The men at the tail relinquish their downward pressure as the aeroplane begins to move, and the tail is drawn away from them. The machine careers off into the wind, rapidly gathering speed. The pilot then runs the engine up to its "taking off" speed—in all probability he will not touch the engine control levers again until a height of several hundred feet is attained, as variations may cause an engine failure, which is dangerous near the ground; after a short climb the engine will be warmer and less likely to missfire, whilst an engine stoppage presents no dangers when the machine has gained a little height.

OVERHAULING THE ENGINE

No directions are given here for the overhaul of an engine whilst it remains installed in the aeroplane. Certain types of engine, notably the rotary, lend themselves to a semi-overhaul of this kind, but no two of them are identical, and the manufacturer's handbook is essential for the job. Consequently, attention will be concentrated on those complete overhauls which are only possible when the engine is removed from its bearers in the fuselage and brought into the workshop.

In the overhaul of aero engines, two points are of prime importance, viz. speed and thoroughness. Speed is vital because an aero engine may cost several thousand pounds, and no firm can afford to have so much capital lying idle. Thoroughness will demand special attention after the war when the double stimulus of military discipline and patriotism is lost; the careless work typical of cheap garage overhauls would be disastrous, and aerodromes will select their men for trustworthiness no less than skill.

When the dismantling squad have cleared the engine ready for removal, it is lifted out of the fuselage by wire slings and overhead tackle and lowered on to a wheeled trestle stand. The slings must be carefully fitted so as not to "pinch" any fragile part when the weight comes on them. A squad of unskilled fitters are then set to work to remove and scrap the hundreds of splitpins with which all the nuts are secured

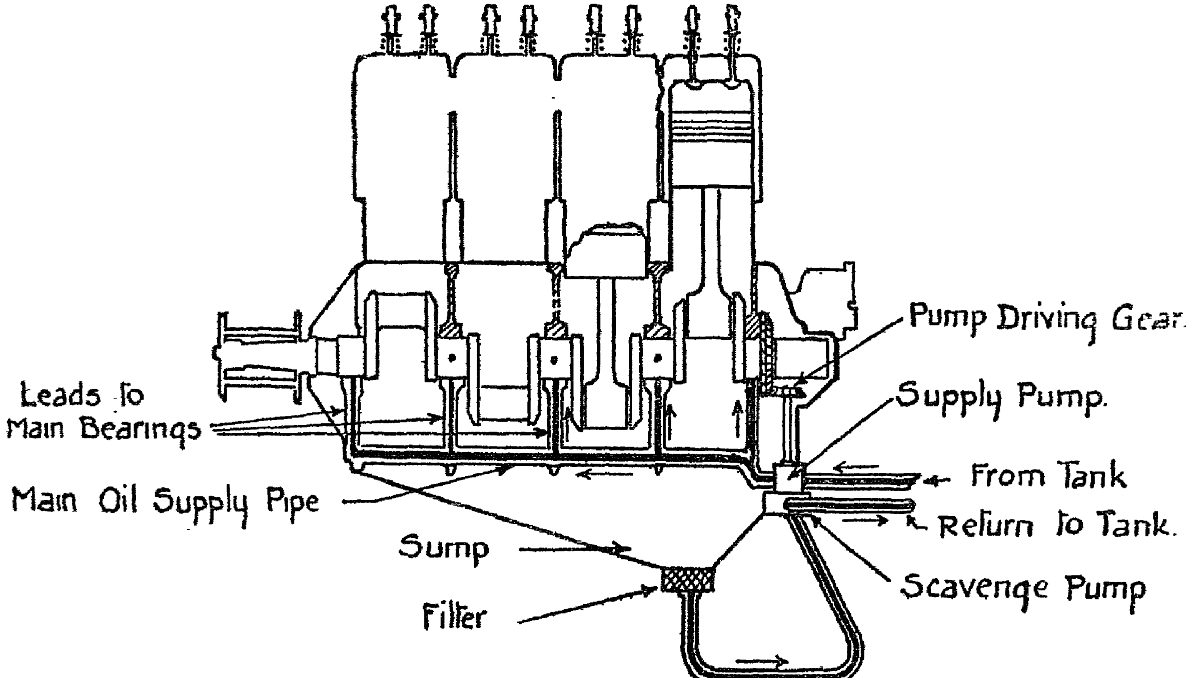


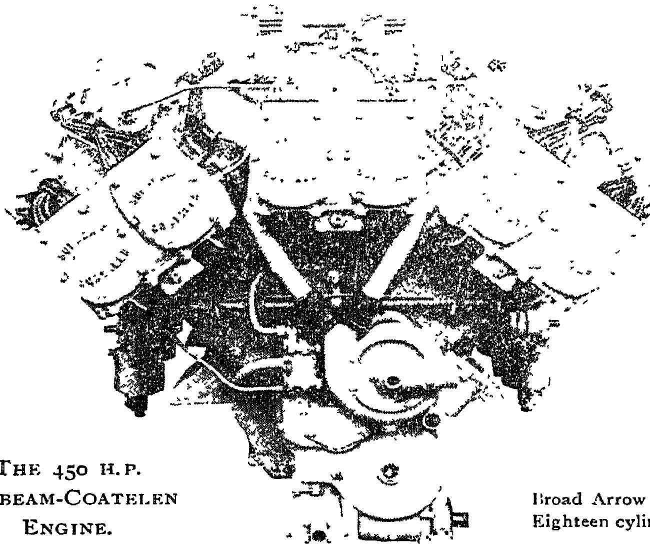
FIG. 1.—Diagram illustrating the "dry sump" system of lubrication.

against vibration; no splitpin must be used a second time. Meantime, a few minor components, such as the carburettors, magnetos, and pumps, may be removed by specialist mechanics if desired, and carried away for test and overhaul. When the splitpins are removed the engine dismantling squad get to work. The engineer in charge will allot the most economical number of hands to the job, and the number will vary according to the size and design of the engine; limited access prevents a large squad from hastening matters. As each part comes away it is thoroughly cleansed in paraffin and stood upon a dustless surface to drain; wiping down with waste or mutton-cloths should be absolutely prohibited, owing to the risk of lint remaining when the engine is re-erected. As the engine comes down, the head fitter will measure the play between the teeth of gear-wheels, bearing-clearances, and other details subject to wear and likely to need extensive repairs. Double inspections will be made of all parts when dry. Replacement parts will be drawn from store. Routine attentions, such as valve grinding, will be carried out. Unless any phosphor bronze or white-metalled bushes require refitting, the engine should be ready for re-erection very soon after the last splitpin is out, as wear in other items generally necessitates a brand new part. If the engine is by a maker of repute, replacement parts should seldom require much "fitting."

The whole of the reassembling work should be closely watched by a highly skilled and completely trustworthy foreman, as any serious error or carelessness may involve the loss of human life.

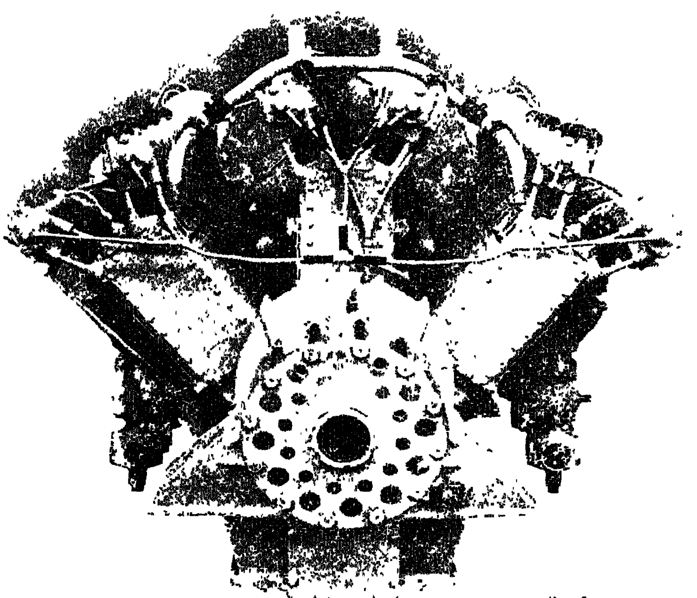
Reassembling is invariably carried out by laying the crank-case on a wooden stand. In the case of a rotary or radial engine, the stand will be shaped like a circular stool, with notches in its edges to clear the cylinders. In the case of a Vee or vertical engine, the stand will be oblong, and consist of legs carrying a pair of wooden bearers resembling those on which the engine is mounted in the aeroplane.

It is impossible to give detailed directions for the reassembling of engines, because the number of makes is already legion and increases daily. The manufacturers of every reputable engine supply an instruction book. Careful study of the special makers' manual, combined with a few hours in the aerodrome workshops, will soon acquaint a quick-witted



THE 450 H.P.
SUNBEAM-COATELEN
ENGINE.

Broad Arrow type.
Eighteen cylinders.



To face page 32.

mechanic with his duties. A few points of special importance in handling aircraft engines are set out beneath.

1. Scrupulous cleanliness is a matter of life and death.

2. Air leaks at the pipe joints between the oilbase and the "scavenge" pump which returns used oil to the tank must be carefully guarded against. Their effect is to fill up the crank-case with oil, and the error may not be discovered until the engine is reinstalled in the aeroplane. Many hours may be wasted by a blunder of this sort.

3. Air leaks at the pipe joints between the carburettor and the engine cause trouble in starting and spoil the slow running; they are avoidable by careful work.

4. Aero carburettors are usually flimsily made of cast aluminium. They must not be roughly handled, or bolted up against a flange which is not perfectly clean and flat.

5. All the tiny oilways in the engine must be blown out with a powerful paraffin syringe. Take no chances in this respect, as a "run" or "seized" bearing may prove very dangerous in the air. Special attention should be paid to any sealed oil-chambers, such as may exist in a crank-shaft. Oil filters must be scrubbed clean. Soft washers at oil joints need careful fitting to prevent obstructions of the flow. High-pressure lubrication systems make great demands on the conscientiousness and skill of the staff; for example, a Hispano engine demands an oil pressure of 60 lbs. per square inch. Such a pressure soon produces leaks at an ill-made joint, and can force a speck of grit into a place where it may do untold harm and wreck an engine worth £1000.

6. Small running parts should be dipped in oil before replacement. Some engineers order all oilways to be charged with oil by means of a syringe before erection, so that lubrication is assured when the engine starts, although the circulation has not yet commenced.

7. Beware of obstructions caused by grease in engines which have been lying in store and were greased all over to prevent rust.

8. Do not handle ball or roller bearings more than is avoidable, as moisture is their chief enemy. When assembling a built-up roller bearing, enter the second race to be fitted with

an oscillating motion, otherwise skid marks will be formed on the rollers.

9. In assembling the long split crank-case of a big Vee or vertical engine, tighten the central bolts first and see whether the crank-shaft turns easily when these bolts are tight. The small bolts along the flange should be screwed home last.

10. Test all the gear-wheels for "backlash" (i.e. play between teeth) during assembly. Serious wear in the teeth affects the timing and leads to breakages in the air.

11. Study the manufacturer's table of "running fits and clearances," with special reference to any parts for the maintenance of which you are responsible. See that the fits are correct as erection proceeds.

12. Master the valve-timing of the engine concerned. Engines vary enormously in this respect; while it is impossible to time certain engines wrong, it is very difficult to time other engines right. The makers' instructions should be thoroughly familiar. No sensible mechanic relies on the "timing marks" stamped on the various teeth, for it is a common occurrence for a new gear-wheel to be fitted during an overhaul, in which case marks are practically useless. All radials, rotaries, and single-line vertical engines are timed by one cylinder; if the key cylinder is timed right the others cannot be wrong. Vee engines are more confusing. If they are timed by "the marks," the makers' book should be mastered, as the marks may or may not imply altering the position of the crank-shaft after timing one "bank" of cylinders. When timing a Vee engine without the aid of marks, commence with the key cylinder of the left-hand block in an engine which revolves clockwise, and with the key right-hand cylinder in an engine which revolves anti-clockwise. After timing the key cylinder two points must be grasped, viz.:

(i) The key cylinder of the block to be timed first fixes the key cylinder of the remaining block, which must always be the cylinder numbered next in the firing order.

(ii) Between timing the two blocks the crank-shaft must be moved forward in its direction of rotation by the number of degrees in the angle of the Vee, e.g. in timing a clockwise Vee engine with its cylinders at 60°, the crank-shaft is moved clockwise for 60° *and no more*, after timing the left-hand cam-shaft.

A protractor disc and pointer are generally used both in performing and verifying the timing. The operator must beware of confusion about the direction in which a shaft revolves. The instructions may give a diagram with an

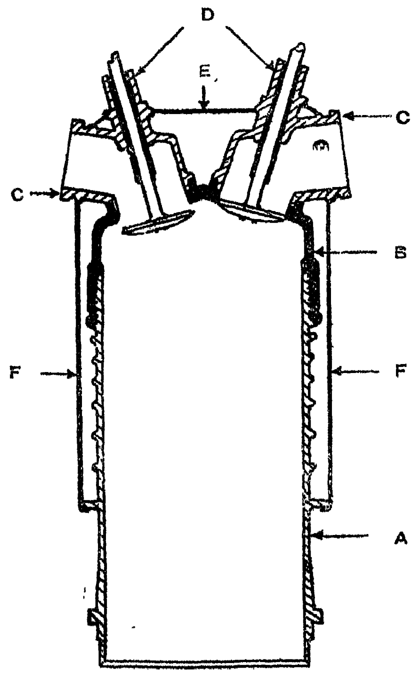


FIG. 2.—Diagram illustrating the construction of a German cylinder, as fitted to the engines of a Gotha raider.

(A) Steel barrel, with stiffening ribs; (B) Steel combustion head, screwed to A; (CC) Steel valve pockets, acetylene-welded into B; (DD) Bronze valve guides, pressed into CC; (E) Steel water-jacket lid, welded to CC; (FF) water-jacket (steel pressing), welded to cylinder.

arrow, or use the standard terms "clockwise" and "anti-clockwise." Sometimes such words as "right-hand tractor" are employed. Arrows and words are alike perplexing, unless the standpoint from which the shaft is viewed is clearly stated; for a propeller which runs clockwise if you stand facing it runs anti-clockwise if you stand behind it.

The writer may seem to labour the pitfalls of valve-timing, but he has personally watched army mechanics in crack squadrons waste hours in attempting to time a strange type of engine correctly. Men are apt to time a familiar engine by rule of thumb, and find themselves hopelessly baffled by a novel pattern. The efficient commercial engineer should be able to time any engine correctly at the first attempt if he is provided with a protractor and the four essential angles at which the inlet and exhaust valves respectively open and close.

13. After the cam-shafts are set, the clearances between the cams and the valve stems, or the rocking levers and the valve stems, as the case may be, are adjusted to fine limits specified in the makers' instructions. This work must be accurately done. Carelessness impairs the running of the engine and produces vibration; if too close a clearance is left at a single valve, expansion may close the gap, and before the machine has flown far that cylinder will be shirking its work. The resultant vibration may compel a landing. In setting the valve clearances of a rotary, special care is needed, as a jamb might conceivably disorganise the entire valve mechanism; in any case the inaction of one cylinder on a rotary engine has disastrous effects. If an engine has two exhaust valves per cylinder, they must open simultaneously. Otherwise the valve which opens first will overheat. In setting valve clearances, perfect memory of the firing order is a time saver, e.g. cylinder No. 7 has just been set on a rotary engine, cylinder No. 9 is the next to reach the adjusting position; the mechanic who is aware of this wastes no time in getting his tappets set.

14. Timing the ignition presents less variations than timing the valves. All engines are timed by cylinder No. 1. The procedure is as follows:

a. Fit the protractor.

b. Turn the engine in its direction of rotation until the crank of No. 1 cylinder is the specified number of degrees before the top of its firing stroke (i.e. that ascent of the piston on which both valves are closed).

c. Turn the magneto shaft in the direction shown by the arrow stamped on it until the distributor brush is in con-

tact with the distributor segment marked " 1 " (as a rule the " 1 " shows through a peephole in the cover).

d. Fine down the magneto setting to the point at which the platinum contacts of the interrupter are just about to separate, with the distributor as in (*c*) above.

e. Couple up the drive from the engine to the magneto.

f. The firing will now be as nearly correct as is possible on the main coupling. A " vernier " setting is often incorporated, e.g. two flanges with very narrow teeth, or two discs with unequally spaced holes and a locking bolt. With the aid of the protractor set the vernier so that the contact-breaker points separate at the exact angle specified in printed instructions.

g. Time the second magneto in similar fashion.

h. It is an excellent plan to wire up an electric lamp into the ignition circuit for a " synchronisation " test. If both magnetos spark at precisely the same instant the engine will run more steadily and perhaps 25 revolutions a minute faster. Synchronisation is too delicate to be performed by eye. As the engine is turned, the lighting up of the bulb will betray any error. The lamp ought to snap in and out; if it fades out the platinum points are rough and dirty.

15. The locking of nuts is naturally far more important than in any other type of fitting. A nut should never be forced home when it is too tight a fit; if a stud is loosened disaster may follow. New splitpins should be used throughout, and the bent-over ends should be properly locked. No splitpin should be bent twice.

16. Oil leaks are obviously tantamount to a crime. They tend to reduce pressure and increase consumption. The oil may conceivably be blown back on to the pilot's goggles and is certain to damage the electrical insulations with which it comes into contact.

17. The most meticulous care is required in assembling the petrol piping and carburettor details. A few weeks ago a pilot was burnt to death because a clumsy mechanic dinted an air intake pipe in coupling it to the carburettor. A backfire occurred, a flame leakage blew through the dent and the machine was burnt to cinders.

18. Similar care is necessary in refitting all the engine controls. If a pin comes out, or a nut is left unlocked, the ignition may become retarded in the air, or the throttle may refuse to reopen after a dive. Whether the pilot can land safely depends wholly upon circumstances.

All aero engine repairs, overhauls, and adjustments should be done in the spirit of the subjoined placard;

REMEMBER

THAT A

SMALL MISTAKE

MAY CAUSE A BRAVE MAN TO LOSE HIS LIFE.

CHAPTER IV

THE AEROPLANE ON THE GROUND

THE war pilot was often a man who neither knew nor cared very much about his machine from a workshop standpoint; and many commanding officers deliberately discouraged their pilots from studying the engine or the aeroplane overmuch, on the ground that nerve might suffer if the pilot knew what might go wrong, and not infrequently did go wrong. In peace time the pilot will be expected to understand every item of his machine from stem to stern, and his employers will value him accordingly. If he can instruct and supervise the ground staff in their many complicated jobs—rigging, adjusting instruments, overhauling carburettors, timing valves and ignition, etc.—the more competent he will be, the greater his value to his firm, and the better chance he will stand of securing a good post when age unfits him for regular flying work.

It is not possible in the compass of this short book to attempt more than an outline of the attention which an aeroplane requires from the ground staff. The learner should realise that a very small percentage of his period at the flying school can be spent in the air; probably his daily average in the finest weather will be less than an hour of flight. Thus he will be able to divide a number of leisure hours between the engine shop, the carpenters' shop, the riggers' squad, and so forth. Indeed, in any well-organised school he will be compelled to attend to these matters.

Commencing with the more elementary details, he should watch an experienced pilot's final inspection and test of his machine before starting up his engine for a flight.

FINAL TEST BEFORE FLIGHT

The following is a representative list, notes being added where necessary :—

1. Tyres properly inflated.

The pilot will test this by eye, judging from the degree to which the walls of the tyres flatten under the weight of the aeroplane. If he is dissatisfied he will call for a pressure gauge and a pump. The correct pressure is specified by the tyre makers. It will not be less than 50 lbs. per square inch, and with big tyres may be as much as 75 lbs. At the same time the pilot will notice whether the slides of the undercarriage have been greased and whether the rubber shock absorber cords look sound.

2. All doors and hinged flaps on fuselage, wings, etc., properly fastened.

Little flap panels are provided to give access to the pulleys of aeroplane control wires, engine oil filters, and other details. If such a flap comes open during a flight, a tremendous wind pressure will be created inside the machine, and may even rip off the fabric or three-ply covering.

3. Undercarriage and tailskid in order.

4. Wires properly tensioned and struts true.

A skilled man, thoroughly familiar with a given type of machine, will "vet. it by eye" as he strolls round it, and detect any serious rigging faults, such as over-tightened wires, slack wires, excessive "droop" of the elevators, too much stagger, struts out of line, etc. The novice cannot hope to achieve this skill immediately, but he should form the habit of testing the tension of wires, lining up all the front interplane struts by eye from one end, lining up each front interplane strut with the corresponding rear interplane strut, etc. These practices are best conducted when a machine comes in from a long flight with several parts ripe for re-rigging, or by examining a machine standing in a hangar awaiting repair.

5. Oil, petrol, and water tanks full.

6. No loose objects in the cockpits.

7. Cockpit covers and picket wires on board.

If a machine sustains a forced landing, and has to be left in a field pending repair, it is usual to fix waterproof covers over the cockpits, and to peg the aeroplane down (see p. 58) so that wind cannot damage it.

8. Controls free and properly adjusted.

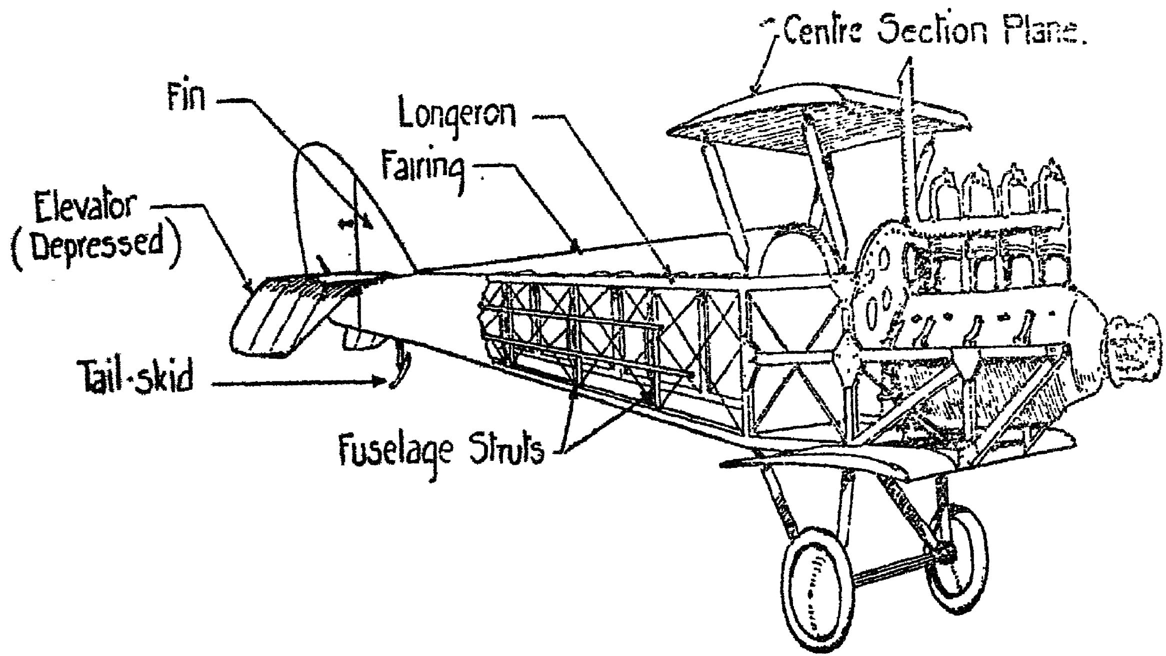


FIG. 3.—Diagram illustrating construction of a tractor biplane.

At this point the pilot climbs into the cockpit and tests all control levers. He sees that his rudder bar lies at right angles to the centre line with the rudder surface central, and that the ailerons and elevators are all in their "neutral" positions when the joystick is central. Then he operates the joystick and rudder, and sees that the controls respond properly without undue backlash or friction being apparent. If a tail trimming device is fitted he tests its working and sets it in the right position for taking off.

9. Instruments correct.

Finally he examines the instrument board. The altimeter and air-speed indicator will require to be set at zero (see p. 106). The working of the map carrier must be free and the correct map installed. The electric lights above the instruments should be tested. If a wireless installation is fitted it will be inspected. The presence of any parachute flares, signal lights, etc., is verified. Then the engine is started up and the engine instruments undergo test in their turn.

RIGGING

After every flight the foreman rigger overhauls the machine very carefully, though he will not find that much requires attention after a normal flight. To a novice the riggers will seem to check the condition of a machine in most haphazard fashion; but after he has seen an aeroplane erected from start to finish he will comprehend that the assembling is most scientifically done, and that a glance from a good rigger's eye or an apparently careless twitch of his fingers is practically the equivalent of a thorough test with special instruments. A rigger uses few tools, but the following are either necessary or useful:—

Several long straight-edges of different lengths; a number of plumb lines; a protractor, or Abney level, for measuring small angles; a tension meter; several spirit levels; trammels (telescopic measuring rods) of different lengths; a step-ladder for reaching the upper parts of the machine; pliers; wire-cutters; spanners; soldering outfit; chalk; long pieces of cord or twine (not too thick); a dihedral board; a try-square; together with a good supply of sailmakers' needles and twine, paint, grease, dope, varnish, and brushes.

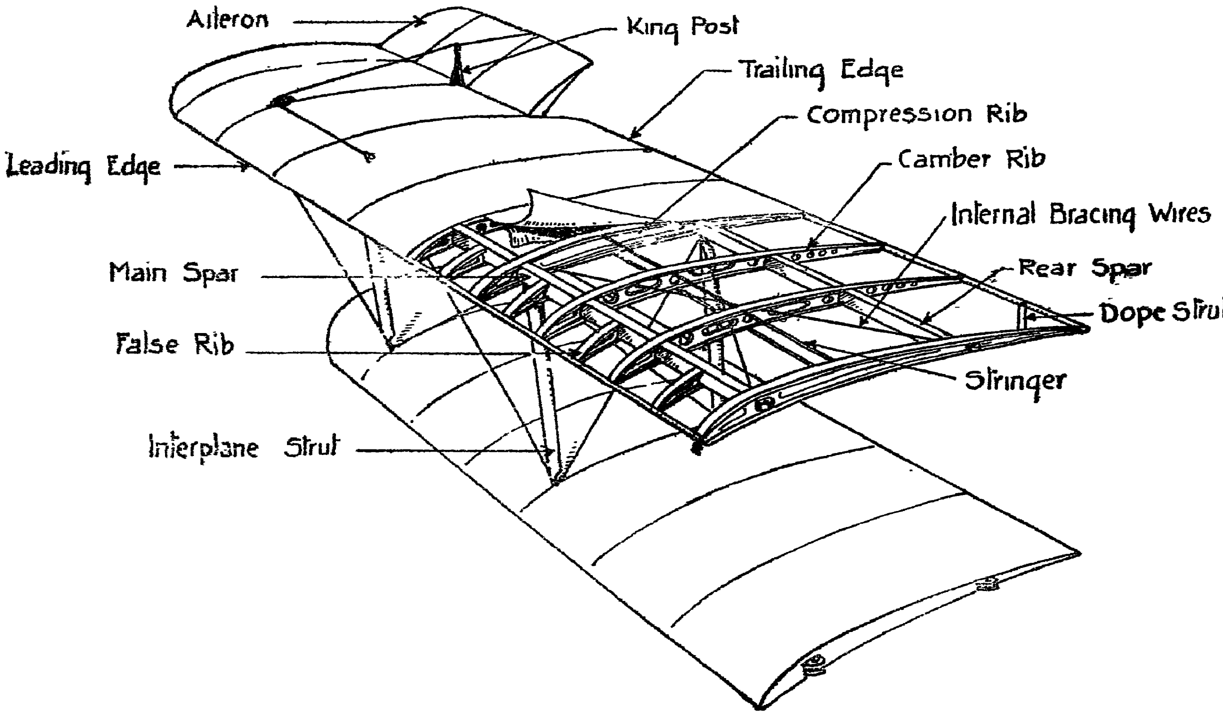


FIG. 4.—Diagram illustrating construction of a wing.

AFTER A FLIGHT

The attention which a machine requires from the riggers after a flight naturally varies. When a war machine comes in from a flight over the enemy's lines, the course of every bullet has to be traced and the exit-hole, if any, found. After a short flight in peace time, under good weather conditions, nothing may need touching, unless the landing was on the heavy side, when the undercarriage will be trued up, and a wire may be replaced. After a violent exhibition of stunting, practically every wire, strut, and surface on the machine may be seriously out of truth. After a mild landing crash, so many parts may require replacing that the entire machine may be taken to pieces. The following list comprises the work implied in a thorough routine overhaul of a tractor biplane.

1. See that the leading edges of the main planes are at the correct angle (usually a right angle) with the fore-and-aft centre line of the fuselage.

2. See that all the bracing wires in the " centre section " are at the correct tension and properly locked.

3. See that the interplane struts are true, all front struts in line, all rear struts in line, each front and rear strut in line.

4. Check the dihedral angle, if any.

5. Check the angle of incidence (main planes and tail plane).

6. See to the tension and locking of all the bracing wires in both wings.

7. See to alignment and bracing of tail planes and fin.

8. Go over all controls, inspecting splices, looking for rust and fraying, pulleys loose or bent. Adjust the control wires, setting ailerons and elevators to " droop " specified by the manufacturer.

9. Inspect under-carriage, wingtip skids, and tail-skid.

RIGGING PRINCIPLES

Fig. 5 is a diagram which illustrates the foundation principle on which an aeroplane is rigged. LL are two of the longitudinal members of the fuselage. They are spaced at a set distance apart by means of the struts SSS, which are said to be in compression, because they are " pinched " between

the two longerons by the pull of the tightened bracing wires, AB, CD, EF, and GH. In all probability the joints between the struts and the longerons depend solely on the pull of the bracing wires. Wherever a strut joins a longeron there is a complicated metal fitting, such as is shown in Fig. 6, which consists of

i. A clip encircling the longeron.
ii. A socket into which the end of the strut beds.
iii. Eyes for the attachment of the bracing wires.

Simple as this joint obviously is, it is enormously strong when it is properly made by the riggers, and absurdly weak if a clumsy rigger blunders over it.

For example, if the clip is screwed down too tightly round the longeron, the longeron will be weakened and must fracture

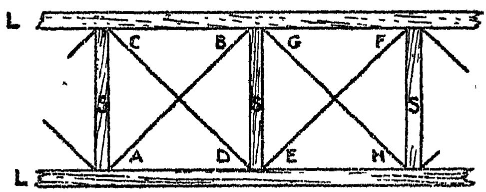


FIG. 5. Rigging the "bays" of a fuselage.

sooner or later ; or if a large washer is omitted from beneath the nut at the end of one of the long clip-bolts, the nut will eat into the wood and the wood will crack or split. Or again, if the head of the strut is not a perfect fit in the socket, the strut will tilt sideways under the pull of the wires or, if it cannot tilt, it may collapse. Or if the wires which slope from right to left are over-tightened, whilst the reverse wires are left a little slack, the struts will be thrown out of the vertical, and the whole structure will tend to collapse towards the left. Or if all the wires are left on the slack side, the whole structure will be "soggy" in riggers' parlance. Or if all the wires are over-tightened the metal fittings at the strut sockets will bite into the wood, which is just as dangerous as over-tightening the clipbolts. The whole of the rigger's job is plainly very complicated. Furthermore, the diagram only shows two "bays" on one side of a fuselage ; there are two similar bays on the opposite side, two more above on

the flat top, and two more beneath on the underside, whilst a fuselage may be eight or ten "bays" in length. The "rigging" of the top, bottom, and far-side bays corresponding with the side bays in Fig. 5 will all influence the rigging of the two bays shown in the drawing. Consequently, the tension of each of the many wires in the aeroplane influences a number of other wires, and after each adjustment

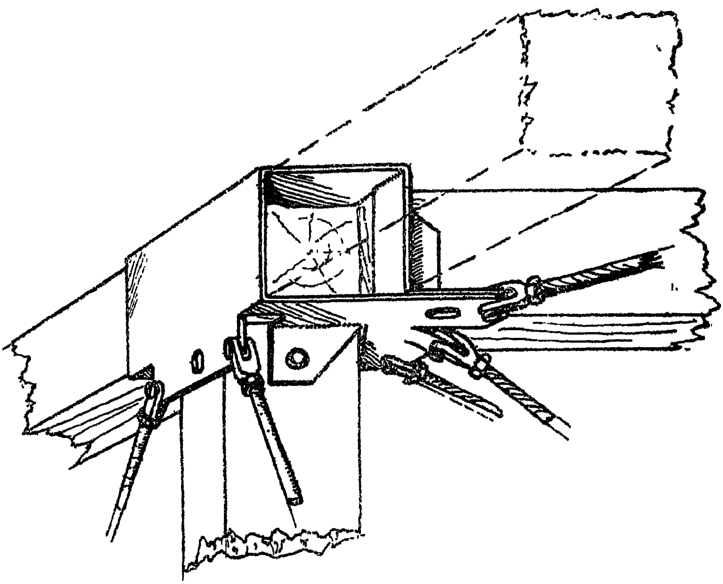


FIG. 6. A wiring plate.
The metal fitting provides sockets for jointing the vertical and cross struts to the longeron, together with attachments for all the bracing wires.

the rigger must check over and over again all other adjustments which may be affected by the wire which he has just set.

TIGHTENING THE WIRES

The wires used for bracing aeroplanes are of three main kinds: piano wire, which is solid wire of circular section; "cable" which is woven out of several strands; and streamline or Rafwire (invented at the Royal Aircraft Factory). Piano wire is attached to the eyes in the wiring plates by

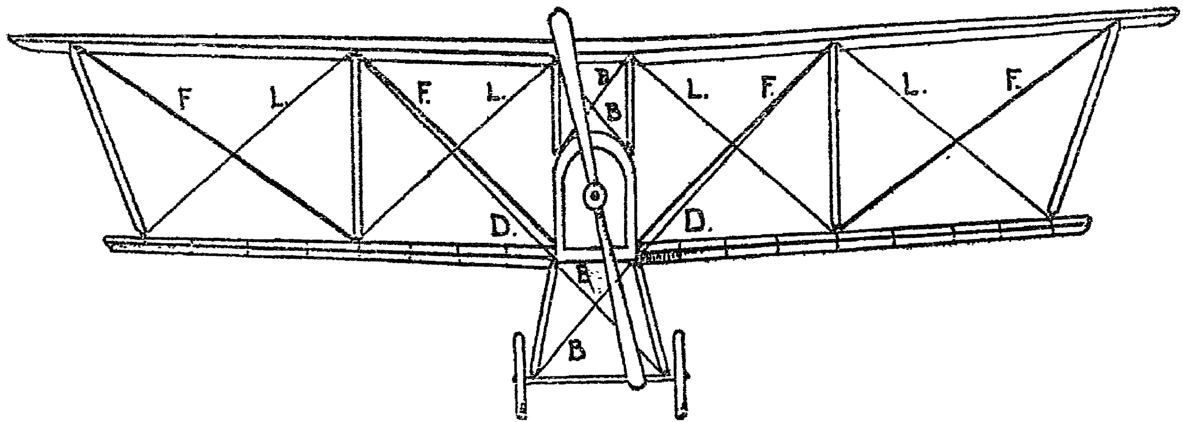


FIG. 7.—Front view of a tractor biplane showing principal wires.

(FF) Flying wires; (LL) Landing wires; (DD) Drift wires; (BB) Bracing wires.

means of loops, formed with the pliers, and locked by slipping on a "ferrule" and turning down the short end of the loop. Fig. 8 illustrates good and bad loops. A large loop pulls out oval in flight and slackens the wire. A shouldered loop

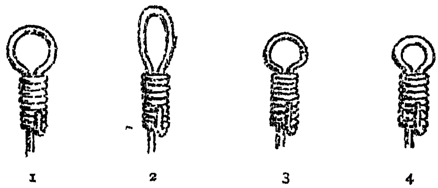


FIG. 8. Loops in piano wire.
1. Too large; will pull out into 2. 3. Shouldered; may break. 4. Good.

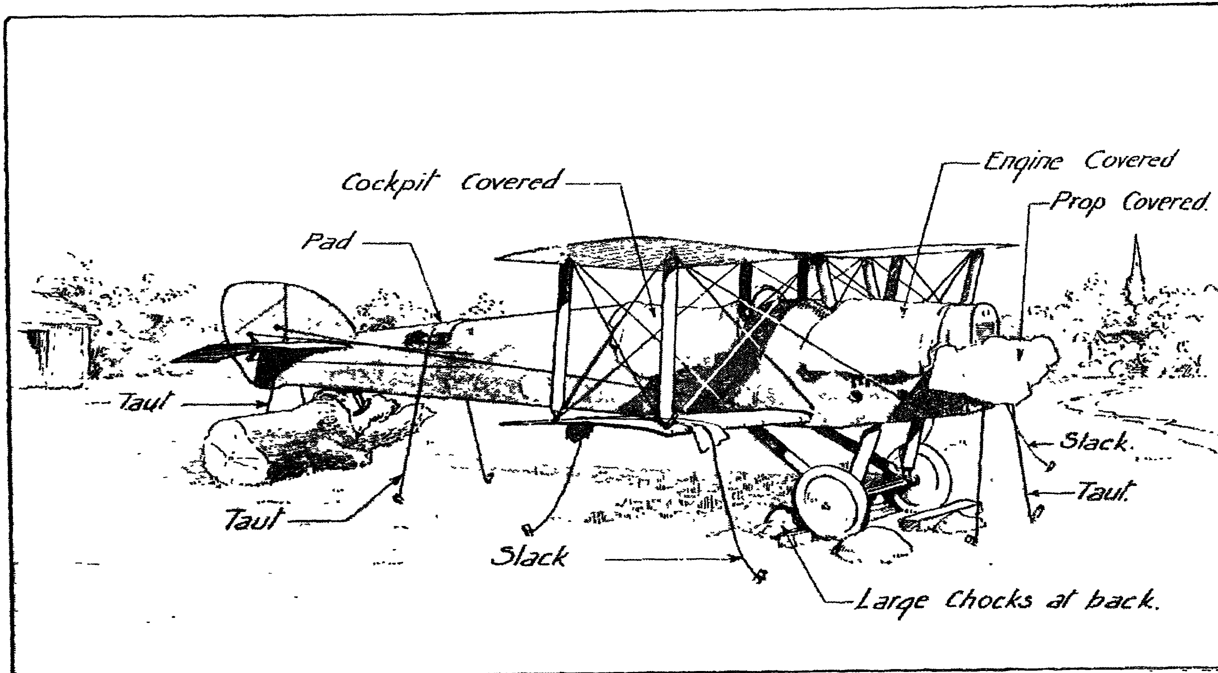
may snap at the sharp angle. A short, rotund loop cannot be improved upon. Piano wire is seriously weakened by rust, or by tool-marks scored on its surface, or by kinks—it must never be bent twice. Cables are bent round to form loops at the ends, and the short end is then woven into the long run by means of a four-point splice; the join is then "served," or wrapped with twine, or perhaps served with thin wire and soldered. Piano wire and cables are usually adjusted for length by turnbuckles (see Fig. 9). Rafwire is made in

FIG. 9.—A turnbuckle, used for tensioning wires.

definite lengths with screw-threaded ends. Occasionally circular tie-rods are used for bracing purposes where the stresses are very heavy; tie rods are fastened by threaded ends. There is a growing tendency to use welded steel tubes for bracing at points of great stress. Struts of wood or of steel tube are sometimes fitted for cross-bracing purposes inside the planes.

VARIOUS RIGGING JOBS

Hundreds of different types of aeroplanes are already in existence, and the number will increase when Government control is withdrawn after the war. The following descriptions are not applicable to every type of tractor biplane, but serve to



How to Peg an Aeroplane down in the Open.

Tail raised, to prevent wind from lifting machine. Nose pointing up wind.

give an accurate outline of the usual procedure. Two preliminary points are of universal application. The first is that every aeroplane manufacturer issues special instructions for the rigger's assistance. For example, it is quite difficult to check an "angle of incidence," which may be defined in its simplest form as the angle between a straight line drawn from the rear edge of a plane to the front edge and the axis of the engine propeller shaft; moreover, this angle may not be larger than $3\frac{1}{2}$ degrees. If a rigger were turned loose on a machine with such instructions as these, his hair would turn grey. So the maker's directions for rigging the angle of incidence may take some such form as "place a straight-edge with its rear end against the centre of the rear spar; set the straight-edge horizontal with a spirit level; drop a

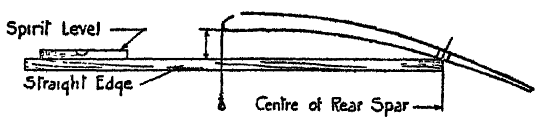


FIG. 10. Rigging the "angle of incidence."

plumbline from the front edge of the plane to the straight-edge; the distance from the wing-edge to the straight-edge, along the plumbline, should be 3 inches." These instructions are easily followed. Manufacturers simplify all the other adjustments in similar fashion. In the second place it is clear that the plumbline measurement just described will vary by many inches according as the aeroplane is standing on level ground or on a hillside or on the usual gently undulating turf of an aerodrome. The rigger guards against such errors by placing the machine in a special position, known as its "rigging" or "flying" position. This position is exactly specified in the maker's drawings or manual, and is generally found by raising the tail of the aeroplane on an adjustable trestle until a datum line on the machine is absolutely horizontal, as tested by a spirit level. The rigger always commences his job by placing the machine in the specified position. During the work this position should be verified at intervals, as the machine is liable to shift.

TRUING UP THE FUSELAGE

This is quite one of the most complicated jobs. The rudder post must be vertical, and the side elevation and top and bottom plans must all be true to the drawings. There are two main keys to accuracy. If the centre points of all the vertical struts in both side views are in the same horizontal plane, the elevation is true; and if the centre points of all the horizontal struts visible in the top and bottom views are in the same vertical plane the plan is true.

The plan view can be trued up in two ways. A simple way is to fasten a long straight-edge horizontally across the nose of the aeroplane and mark its centre and two points equidistant from the centre, one on each side. Measurements

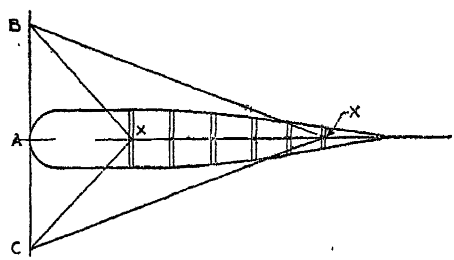


FIG. 11. Rigging the fuselage (plan view).
All measurements from B to the strut centres (e.g. XX) must equal the corresponding measurements from A.

can then be made from both side points to a variety of points selected along the centre line of the fuselage, and covering the entire length from the nosepiece to the rudder post. Adjustment is continued until the corresponding measurements on both sides are equal. Alternatively, a plumb-bob may be dropped from the propeller boss and from the rudder post, sticks set up in line with the plumbs, and a string made taut from end to end between the sticks. A plumbline is then dropped from the centre of each horizontal cross-strut in the fuselage; and adjustment is continued until all the plumbs are lined up along the taut fore-and-aft string.

When the plan is true, the manufacturer's drawings or printed instructions must be consulted, as the side view or elevation of a fuselage is never wholly rectangular, and the

vertical side struts must therefore be trued to some selected horizontal line, and not by their tops and bottoms. A string is made taut to whatever horizontal line is specified by the manufacturer, and specified points on all the vertical struts

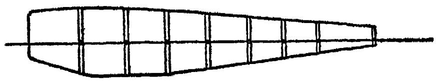


FIG. 12. Rigging the side elevation ot the fuselage.

on both sides of the fuselage are trued up to the datum line represented by the string.

Throughout the above and following processes, each bay should be separately checked as the work proceeds by means of a trammel and try-square. The trammel is a telescopic measuring rod, and when the two diagonal bracing wires in any particular bay have been set for tension, the trammel

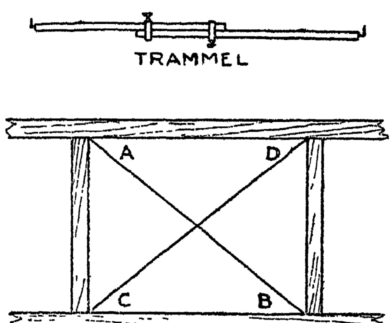


Fig. 13. Tuning up a bay with the aid of a trammel. Measurement AB must be equal to measurement CD.

shows whether they are of the same length, as the diagonals of a perfect square must be. If the trammel shows that the wires are of different lengths, the try-square will show whether the bay is out of square or whether the wires are falsely cut and cannot be equal in tension.

The fuselage bracing wires are preferably adjusted in the following sequence: (i) inside wires, (ii) top wires, (iii) wires on one side, (iv) wires on the other side, (v) wires on bottom.

When the job is complete, make a final check of the plan and elevational truth, see that the rudder post is still vertical, and test whether the points of attachment for the spare of the main planes are at the correct angle. Before proceeding

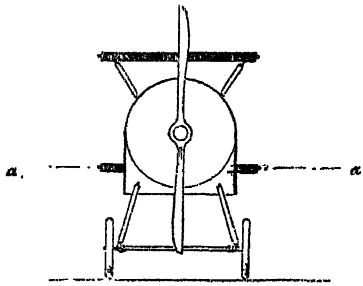


FIG. 14. See that the points of attachment (*aa*) for the spars of the lower planes are horizontal (or at the specified angle).

with the rigging, verify the "rigging position," supposing that the machine was set up before the fuselage was rigged.

RIGGING THE UNDER-CARRIAGE

As any readjustment of the undercarriage is liable to affect the "rigging" position, the undercarriage is tackled before the main planes. Trammel the cables and see that the axle is at right angles to the fuselage. Take this opportunity to inspect the shock absorber, to grease any sliding parts, and to direct the attention of the tyre fitter to any fault in the tyres.

LINING UP THE WINGS

The centre section is first put in position and its struts fixed to their sockets. If it is not trued up with great accuracy difficulty will be encountered when the wings are erected. It must be correct in the following respects :

i. Stagger (if any) ; plumbline is dropped from front edge of top plane ; distance from plumbline to datum point in maker's instructions verified.

ii. Incidence. Set by straight-edge and Abney level (this instrument is a combination of a protractor and a spirit level), or by maker's directions.

iii. Square, so that centre of centre section plane is in line with centre of fuselage.

When the centre section has been rigged, the wings are bolted up; each wing, consisting of an upper and a lower main plane, is usually assembled prior to installation.

The various settings are described below:

1. Angle of incidence.

Test as in Fig. 10, or with Abney level. Repeat test under every pair of spars. If it is wrong, attempts to correct it by altering the incidence wires only will spoil the tension of all the wires running to the struts concerned. Suppose the

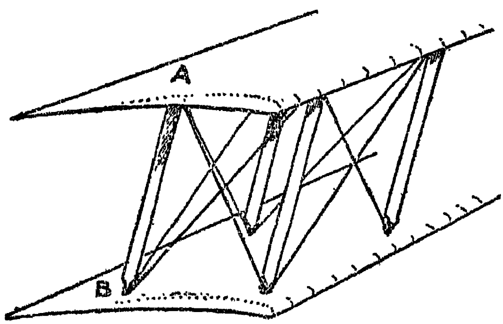


FIG. 15.

correct angle is 5 degrees and the setting is found to be 6 degrees. Correction is always made by means of the rear spar (i.e. the hinder longitudinal member of the plane). As the actual angle of 6 degrees is too large, this spar has to be warped *up*, in other words, all the wires which run to the foot of the rear strut have to be tightened. But these wires cannot be tightened until the wires which run to the top of the strut have been relaxed a little. So the procedure is as follows:

i. Relax all wires anchored to top of strut (A).

ii. Tighten up all wires anchored to foot of strut (B), commencing with the incidence wire which runs from B to the top of the front strut; tighten these until the Abney level shows that the angle is correct. Then tighten up the other wires to the foot of the strut.

iii. Tighten up the wires anchored to the top of the strut.

On the other hand, if the angle of incidence were found to be too small, e.g. 4 degrees, the wires to the top of the strut must be tightened, after relaxing the wires to the base of the strut; in this case, the key to the adjustment will be that incidence wire which runs upwards towards the rear.

In setting the incidence, the operator must not forget to measure the angle under each pair of struts (i.e. one front and one rear), or to allow for any alterations in the incidence towards the wing-tips, which is generally called "wash-in" and "wash-out."

2. Stagger.

A pair of planes are said to be "staggered" when their front edges are not in the same vertical line. It is always measured by dropping a plumbline and taking a measurement

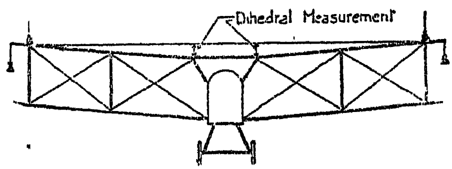


FIG. 16. Rigging the lateral dihedral angle.

quoted in the maker's instructions. If the top plane projects beyond the lower plane ("forward stagger"), the line will be dropped from the front edge of the top plane, and the measurement will be taken from the line to the front edge of the lower plane, either along a horizontal line (straight-edge and level) or along the chord of the lower plane (straight-edge across front and rear edges of bottom plane). With backward stagger (lower plane projecting forward of upper plane) special instructions are provided by the makers.

3. Dihedral.

Some riggers use a dihedral board, which is a small flat stool, with its underside or feet bevelled off to the desired angle, and its top flat. This is placed on the spars at numerous points, with a spirit level resting on the board. It is an easy instrument to use, but wooden articles readily warp, and if the board is true the spars are not likely to be absolutely true from end to end. A more tiresome but sounder method consists

of taking a long cord, weighted at both ends, and stretching it clean across the plane, as shown in Fig. 16. A heavy weight is placed at one end, the string is pulled taut and weighted at the opposite end. The distances at the arrows are then measured, and should correspond with a dimension specified by the maker.

EMPENNAGE OR TAIL ASSEMBLY

These parts are easily rigged and checked over by the aid of the spirit level, plumbline, straight-edge, and trammel. If the incidence of the tail plane is adjustable, as often happens, information should be sought from the pilot. Adjusting devices are of two kinds ; sometimes the angle is set by means of a pin and series of holes ; sometimes the pilot has a control wheel by which he can vary the incidence during flight. In the latter case, the rigger sets the tail at the centre of the control range ; in the former case he consults the pilot, who will require a special angle to suit the weight and disposition of the load which he intends to carry.

RIGGING THE CONTROLS

Lash the rudder bar at right angles across the fuselage and fasten the joystick in its central position, Tighten the cables until the controlling surfaces are in the positions specified by the maker, i.e. the rudder central, the ailerons and elevators lying out as continuations of the main and tail planes respectively, unless the instructions specify a little " droop " or hang. During these preliminaries the upper and lower cables controlling each aileron and elevator will be approximately equalised in length, and the same applies to the port and starboard rudder cables. It still remains to perfect the adjustment. If the cables are too tight, the pilot will find it hard work to operate his controls, the cables may jamb, and the pulleys may be wrenched adrift from their fastenings. On the other hand, if the cables are too slack, the moment of delay before the resistance comes on the rudder or joystick will prevent the pilot from operating the controls with a firm, steady movement ; neither will the controls give him full warning when a " stall " is imminent. A good rigger sets his controls so that they work easily, and yet the surfaces begin to respond before the joystick or rudder has moved more than a tenth of an inch out of centre.

This is a fiddling little adjustment, but the pilot's trust in a man who does it well is a satisfactory recompense.

CONCLUDING THE JOB

An inexperienced rigger or squad will certainly not succeed in the above complicated series of operations at the first attempt. Skilled hands find it necessary to check and re-check every adjustment over and over again, as the job proceeds. In particular, the following final checks must never be omitted :

i. Check the overall measurements (as in Fig. 17).

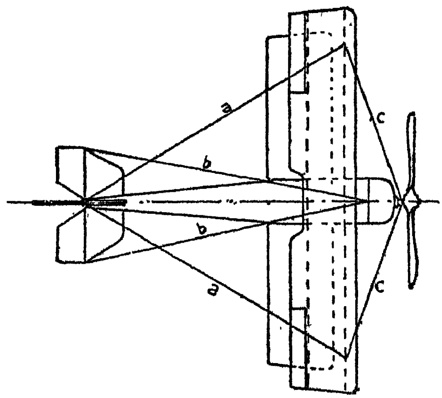


FIG. 17. Checking the overall measurements after rigging the machine.

ii. Check the stagger, incidence, and dihedral, as the final tightening in this series sometimes disturbs the earlier settings.

Last of all, a careful rigger will inspect the entire machine, and note whether all wires are tight, whether all turnbuckles are properly locked, and whether all nuts are firmly secured.

OVERHAUL AFTER A FLIGHT

Given a careful pilot and a squad of skilful riggers, the lengthy operations already described will not be necessary after every flight. As a rule, inspection by a foreman rigger will be taken as a sufficient precaution except where a racing

machine demands the last atom of efficiency, or when a very long flight is anticipated. A summary of advisable routine attentions between flights is set out below.

1. See that wings are at correct angle to fuselage.

2. Check stagger, dihedral, and incidence, including wash-in and wash-out.

3. Inspect all bracing wires in centre section and wings.

4. The adjustment of all control wires and surfaces and the soundness and working of all control cables should be tested.

5. Go over undercarriage carefully.

HANDLING A MACHINE ON THE GROUND

A variety of trolleys and trestles are used for moving machines about in hangars and on the aerodrome, especially with the modern multi-engined machines, which are frequently towed by small petrol tractors. The pupil should use his eyes, as there is a particular reason for doing things in a particular way. Aeroplanes must only be man-handled by their strongest parts; and stupid handling may cause such important injuries that many British makers paint the words "Lift Here" on special parts of the fuselage, whilst German makers go so far as to put spikes or saw-edges on tempting parts which ought not to be held when a machine is lifted or pulled. Broadly speaking, a spar is weak except where it joins a strut, and a strut is weak except where it joins a spar. The following rules should be observed:

1. Pull or push machine by placing hands at base of an interplane strut.

2. Lift the tail by placing hands under the bases of struts (visible through fabric).

3. Lift a wing by making a leap-frog back under the point where a strut is socketed into a spar.

IN THE REPAIR SHOP

The pupil should obtain lessons in patching and doping damaged surfaces. He should also watch carefully how turnbuckles are adjusted and locked; in the latter case the direction in which the locking wire is wound is important. He should watch how a new strut is fitted to a socket, its butt being covered with paint and tested for bedding. He should practise making loops in piano wire, which is an art in itself.

PICKETING A MACHINE OUT OF DOORS

Sooner or later he will be compelled to "picket" his machine in an open field after a forced landing, so it will pay him to go out with the repair gang at the first opportunity and to take careful notes of how the machine is secured. The machine should be stowed head to wind under the lee of any available shelter, and the tail should be jacked up, if possible, so that the main planes present a low lift angle to the wind. Stones from a wall, shocks of corn, or piles of turf may be utilised as a makeshift trestle. The machine is then

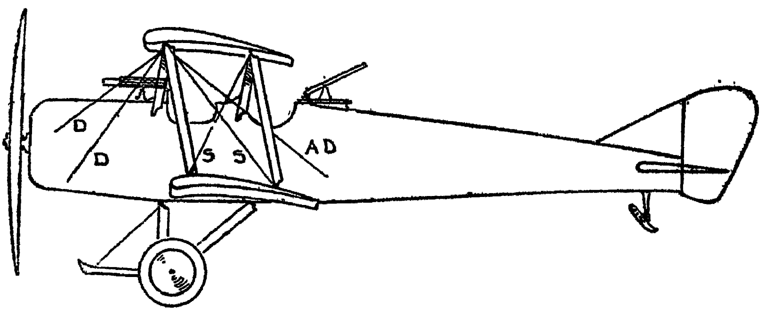


FIG. 18.—Side view of two-seater tractor biplane, showing wires.

(DD) Drift wires; (AD) Anti-drift wire; (SS) Stagger or incidence wires.

lashed so that it cannot move to and fro, slew round, or rock from side to side. The wind will try to lift the machine backwards, and the wheels should be well chocked with stones. Pegs should be driven deep into the ground so as to come at right angles with the ropes attached to them. Lashings and pegs should be secured to (a) the nose; (b) the wing-tips; (c) over the tail. Wherever ropes are passed and strained over flimsy portions of the machine, e.g. fabric-covered surfaces, pads of grass, cockpit cushions, etc., should be interposed when possible. The wing-tips should have double ropes, secured up wind and down wind respectively; a little play may be left in these lashings, so that the machine can rock a little, which is less dangerous than any tendency

to lift. The cockpit should be covered, and, unless help is at hand, the propeller may be removed and stored in any convenient shelter.

ERECTING A NEW MACHINE

The following is a manufacturer's specification of the manner in which a machine should be erected from its component parts :—

1. Assemble and true up rear section of fuselage.
2. Assemble and true up front section of fuselage.
3. Join and align the two sections of fuselage.
4. Fit undercarriage.
5. Fit control mechanism in fuselage.
6. Fit tailskid.
7. Fit oil and petrol tanks (inverting fuselage).
8. Mount engine.
9. Fit engine controls.
10. Fit oil piping.
11. Fit dashboard and instruments.
12. Fit engine cowling.
13. Place machine in rigging position.
14. Mount and true up centre position.
14. Mount and true up centre section.
15. Fit tail component (fin, tailplane, elevators, rudder).
16. Fit fairing.
17. Fit and adjust control cables from rudder bar to tail-skid.
18. Fit and adjust elevator and rudder controls
19. Lace fabric over fuselage and dope.
20. Erect main planes and true up.
21. Fit and adjust aileron controls.

CHAPTER V

FLYING WITH AN INSTRUCTOR

AT last the great day arrives when the pupil is told to make his first flight on a "dual control" machine with an instructor; both the instructor's and the pupil's cockpits are fitted with the necessary appliances for controlling the machine in flight. Before he goes up he will have acquired full theoretic knowledge of the various controls, the purposes they serve, and how to operate them. These matters are dealt with in *Aeroplanes and Aero Engines*; only the briefest summary will be given here. The essential controls are five in number, viz. :—

Engine Controls . .	1. Switch. 2. Throttle.
Aeroplane Controls . .	3. Elevators. 4. Ailerons. 5. Rudder.

1. Switch.

This closely resembles an ordinary electric-light switch; its "on" and "off" positions must be learnt. It controls the ignition current, and the pupil will not be concerned with it until he flies alone.

2. Throttle.

This controls the speed of the machine in exactly the same fashion as the "accelerator" of a motor-car. It cannot stop the supply of gas to the engine completely, being set so that the engine will continue to run slowly when the throttle lever is in the position marked "closed." As the lever is advanced from the "closed" towards the "open" position, an increasing quantity of gas is admitted to the engine and more power is developed. The instructor will probably forbid the pupil to touch the throttle until he is quite at home in the air.

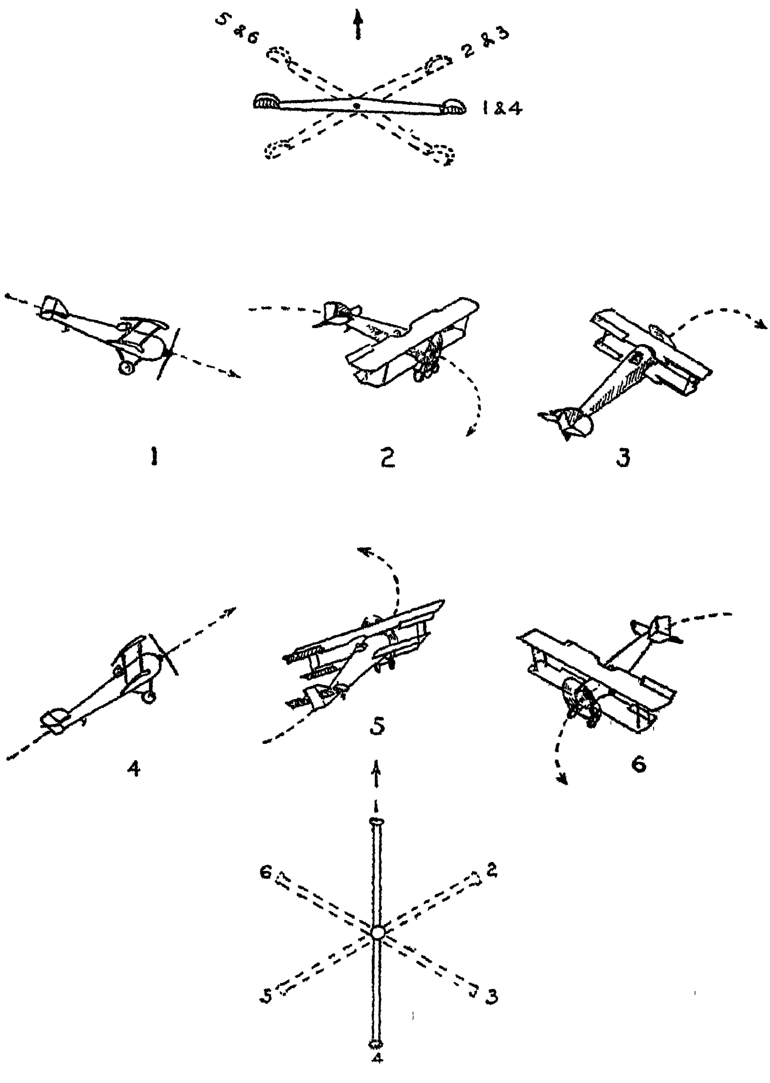


FIG. 19. Diagram illustrating control positions of the aeroplane.
Top: Rudder bar. Bottom: Joystick.

1. Straight descent.
2. Descent, with right-hand turn.
3. Climb, with right-hand turn.
4. Climbing straight.
5. Climb, with left-hand turn.
6. Descent, with left-hand turn.

3. Elevators.

The elevators are miniature planes or flaps hinged to the rear edge of the tailplane, and are used for making the aeroplane climb or dive. When they are pulled down increased lift is imparted to the tail of the machine, which rises, levers the nose of the machine downwards, and causes it to lose height. When they are pulled up the lift of the tail is decreased, and it drops ; the nose of the machine goes up, and

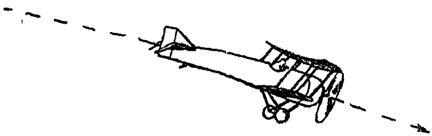


FIG. 20. Elevators pulled down, tail forced up, machine dives.

it climbs. The elevators are controlled by the "joystick," which is mounted on a rocking joint between the pilot's knees. When the joystick is moved forwards in a straight line it pulls the elevators down and the machine dives ; when the joystick is pulled back the elevators are raised and the machine climbs. It will be noticed that these movements are natural, i.e. the pilot naturally sits back when he is climbing and vice versa.

4. Ailerons.

The ailerons or wing-flaps are miniature planes or flaps hinged to the rear edges of the wing-tips of the main planes. Ailerons may be fixed to both the upper and lower planes of a biplane, or to one plane of each wing only. The joystick

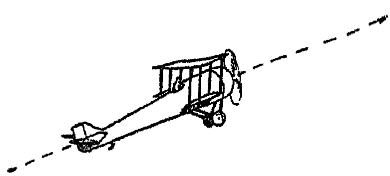


FIG. 21. Elevators pulled up, tail drops, machine climbs.

controls the ailerons as well as the elevators. They are coupled together by levers and wires in such a method that the right-hand aileron is pulled up when the left-hand aileron is pulled down, and vice versa. The ailerons on both sides are

in the " neutral " or flat position whenever the joystick is on a line drawn down the centre of the aeroplane from its nose to its tail, and the joystick does not move the ailerons unless it is pushed to the right or left. Pushed to the right, the joystick lowers the left-hand ailerons ; the left-hand wing-tip

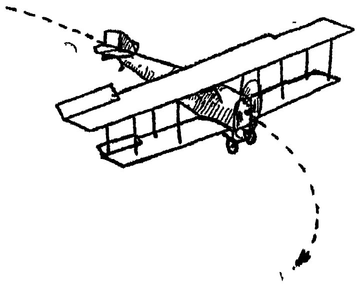


FIG. 22. Left-hand aileron pulled down, left-hand wing-tip rises, machine banks over for a right-hand turn.

is thereby raised, and the aeroplane is canted, or " banked," over for a right-hand turn, just as a cyclist leans to the right for a right-hand corner. Similarly if the joystick is pushed over towards the pilot's left, the right-hand aileron is lowered, the right-hand wing-tip is raised, and the machine banks over for a left-hand turn.

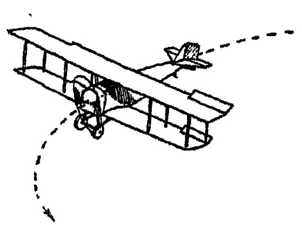


FIG. 23. Right-hand aileron pulled down, right-hand wing-tip rises, machine banks over for left-hand turn.

At the outset the instructor will demonstrate the simplest motions of the joystick only. He will move it fore and aft to descend or climb, and he will move it sideways to turn right or left. But he will not confuse an excited pupil by moving it forwards and to the right simultaneously. It is obvious that the rocking mount of the stick makes any com-

bination of the fore-and-aft and sideway movements possible; and presently the instructor will begin to teach such combined movements. They are easily understood, even on paper. Thus, the machine always descends when the stick is pushed forwards, and it always banks to the right when the stick is pushed to the right; therefore, if the stick be pushed forwards *and* to the right at one and the same time, the machine will go down and turn to the right as it descends.

5. The Rudder.

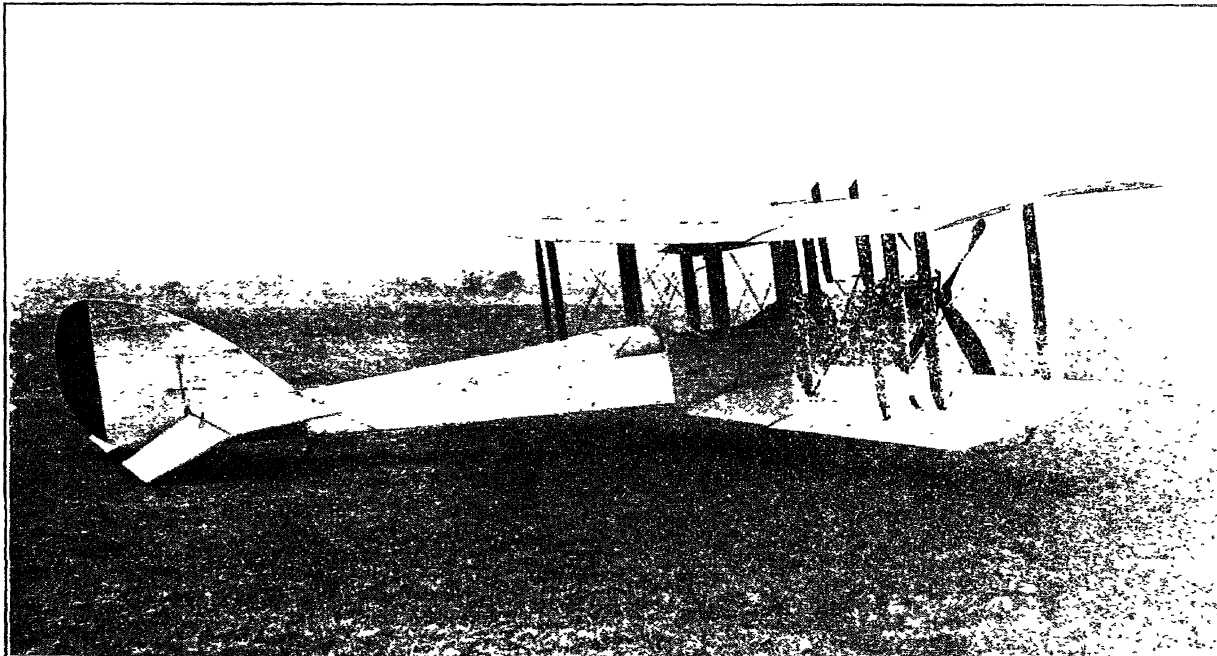
When a cyclist turns to the right he performs two separate but allied motions:

1. He cants his cycle over towards the right.
2. He turns his front wheel to the right.

An aeroplane is turned by two similar movements. It is banked over by means of the ailerons towards the inside of the proposed turn, but this banking does not suffice—if the cyclist leant over without turning his steering-wheel he would fall over or sideslip. So the rudder of the aeroplane is turned to the right while the machine is canted over to the right. The rudder control consists of a short crossbar, conveniently mounted under the pilot's feet, and responding to pressure by turning on a central pivot. When the right foot is pressed forwards the vertical rudder at the tail of the machine projects across the air stream on the right-hand side of the aeroplane, as shown in Fig. 19. The machine is travelling forwards at perhaps 80 miles an hour, and the heavy pressure forces the nose of the machine over to the right.

The pupil will have familiarised himself with the theory of these controls by means of books, and with the action of the joystick and rudder bar by sitting in the cockpit with the machine at rest in its hangar. But until his first flight he is in the position of a man who has never been in a motor-car, but is aware that it is steered by turning a wheel. Consequently, the main purposes of the first flight are two in number: first, to familiarise the beginner with the sensation of being in the air; secondly, to accustom his muscles to the correct movements of the joystick and rudder for making sundry of the simpler changes of direction in flight.

For this reason, the first flight is made in a "dual control" machine. Each of the two cockpits contain a separate joystick and a separate rudder. Both joysticks are connected



A DUAL CONTROL TRAINING MACHINE OR "SCHOOL BUS."

The D. H. 6 Aeroplane (Aircraft Manufacturing Co.) on which many R.A.F. Pilots learn to fly.

To face page 64.

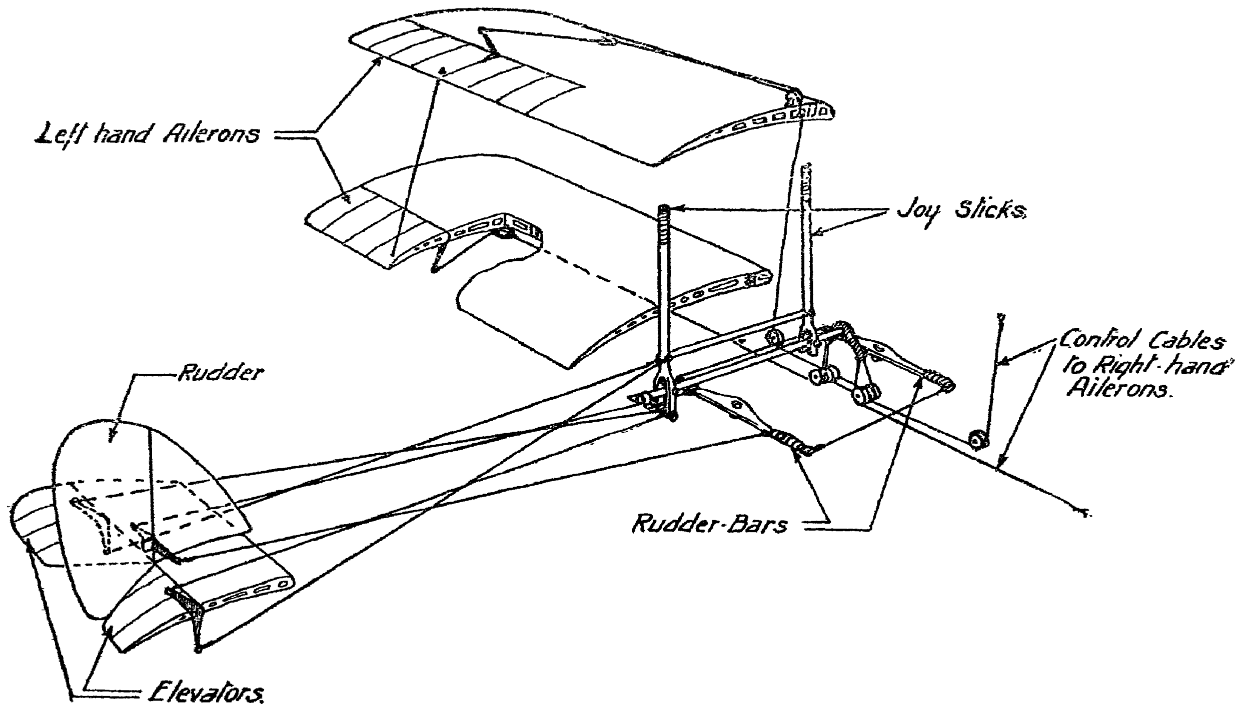


FIG. 24. Diagram of the dual control fitted to a school machine.

to the ailerons and elevators, both footbars are connected to the rudder ; i.e. the pupil's controls are not dummies. On some school machines the controls in the instructor's cockpit are given additional leverage, so that he can overpower a pupil who loses his head and does something silly ; in others both sets of controls are equally powerful.

The pupil is taught to grasp the joystick very lightly and to rest the soles of his feet very gently against the rudder bar. At the outset he will not attempt to control the machine, but his controls will of course follow the movements of those in the instructor's cockpit, and he will learn by feel exactly how to effect any desired change of direction.

Presently the instructor will be satisfied that his pupil's nerves are normal, and will intimate that the pupil shall attempt to fly the machine. The method of communication varies with the different types of training machine. In some the cockpits are very close together and the instructor places his hands on the pupil's shoulders and indicates "up," "down," "right," or "left" by pressure on the pupil's shoulders ; other patterns are equipped with speaking tubes, and communication is by word of mouth. The pupil need not feel nervous. On an average there is not more than one accident in every 125,000 miles of flight ; the instructor values his own life, and will have formed a favourable judgment of the pupil before he entrusts control to him ; in any case, the machine will certainly be high enough for the instructor to correct any blunder by means of his own controls before the consequences threaten any danger.

The first flight will be disappointingly short, because the instructor is too wise to tire a beginner, for whom everything is novel. Before going up again the pupil will have time to sort out his impressions. He will principally be struck by the smallness and lightness of the control movements in contrast with the fierce wrenches which he probably supposed were needed to control a fast and cumbrous aeroplane. In the second place he will notice that the joystick and rudder must be "centralised" after correcting the course of the machine ; this ought to be obvious, since, for example, a motorist straightens his steering-wheel after taking a corner, but many flight pupils instinctively leave their rudders on after finishing a turn and expect the machine to resume level flight when the joystick is out of centre.

On the next flight, the pupil will probably take over complete control as soon as the instructor has climbed the machine to a safe height. He will now be reminded of his first essays in steering a motor-car. From the pavement it appears that anybody should be able to get into a motor-car and steer a perfect course without an atom of trouble. But the novice finds it impossible to steer a motor-car dead straight or to take corners perfectly for the first half-hour or so. Much the same applies to flying, even when the air is entirely free from "bumps." At the first attempt it seems hopeless to fly dead straight. The machine dips up and down with a rising and falling flight, like a finch. Its nose keeps turning a shade to the right or left of the desired course, like a badly steered wherry. It keeps drooping first one wing and then the other. When the budding pilot conscientiously and earnestly uses his controls to correct all these tendencies, he usually overdoes matters. His hands and feet are kept busy all the time, and his brain is anxiously working to prevent a false movement of the joystick or rudder; yet the machine obstinately insists on following a perfectly scandalous track. The pupil probably lands in a state of extreme depression, convinced that he will never, never, never be able to fly neatly and well.

Meanwhile, his muscles are accommodating themselves to the necessary adjustments, and on the next essay he will astonish himself by flying a very creditably straight mile. Then his tribulations recommence. The instructor next proceeds to make turns, and though the pupil "feels" all the movements through his hands and feet on the duplicate joystick and rudder, his first few turns are ungainly to a degree. He puts on too much bank or too little rudder, and despairs of ever judging the combined movement of joystick and rudder bar at all accurately. A sensible instructor will conclude the second flight by another straight mile with the pupil in control. When the tyro lands he will comfort himself, "Well, yesterday I couldn't even fly straight. I am getting on, and perhaps to-morrow I shall be able to turn." To-morrow he makes a number of tolerably good turns, and at last he approaches the hardest task of all—landing. For this purpose the instructor will probably make repeated circuits, rising against the wind and landing against the wind on each trip. The pupil will merely "feel" the first few

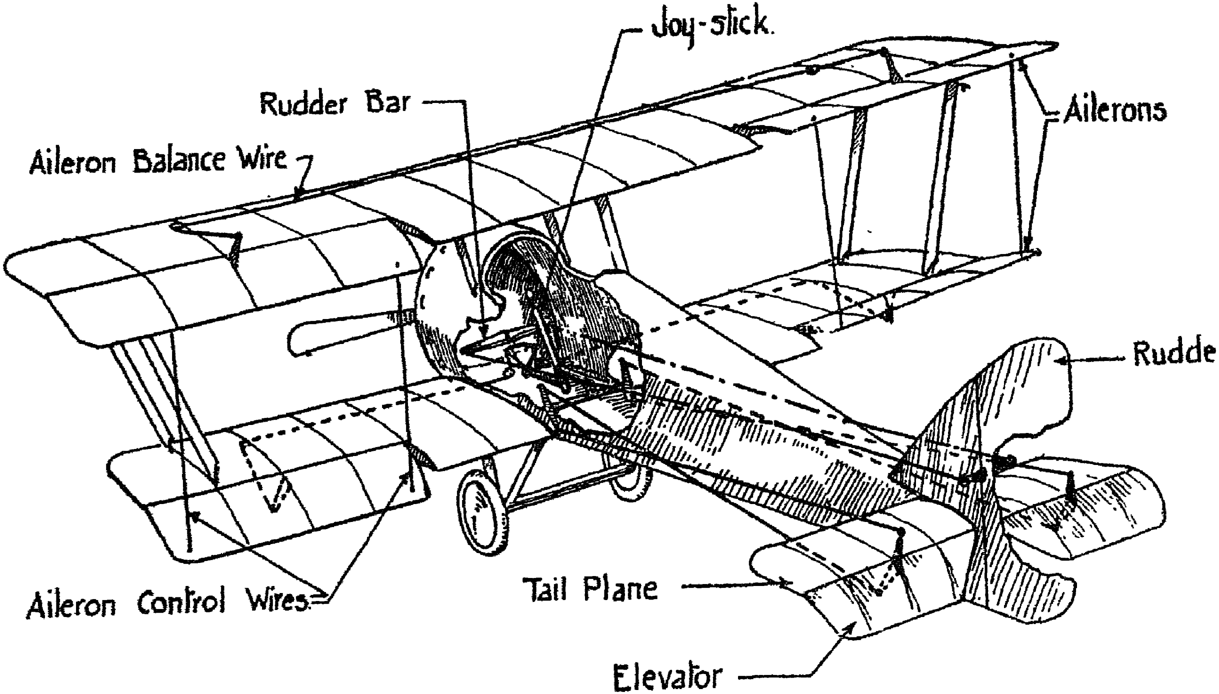


FIG. 25.—Diagram showing the standard controlling surfaces, levers, and wires.

landings, and then he will be told to do the work himself, with the watchful instructor gripping the other controls lightly but warily, ready to save the situation if required. Landing is performed as follows:

1. Judge the spot from which the glide down to the landing ground must commence. (On the first few trials the instructor will probably decide this point.)

2. Either switch off or throttle down the engine, according to instructions. The machine cannot, of course, descend when the engine is pulling hard; it must either be stopped altogether, or throttled down till the power produced is insufficient to affect the aeroplane. There is much to be said in favour of both alternatives. If the engine is switched off, the risk of a fire following a landing crash is reduced; but if the engine is left ticking over, it can be opened up

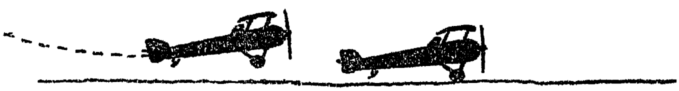


FIG. 26. A good landing.

The aeroplane is flattened out just above the turf, and runs off its impetus, making almost imperceptible impact with the ground.

after a misjudged glide, so that the machine can rise again, come round into the wind, and make a fresh attempt. Pupils will, of course, have this matter settled for them by the instructor. A sound compromise consists of throttling the engine down when the glide is commenced, and switching it right off as soon as a good landing is assured.

3. The instant the engine is stopped or slowed down the nose of the machine is put down by pushing the joystick forwards. The instructor will have indicated the correct angle and will reset the stick if the pupil misjudges it. All aeroplanes are "nose-heavy" with their engines stopped, and gravity causes them to glide down at a gentle angle in perfect safety. The speed is, however, tolerably high—possibly 50 miles per hour, or even more; and the difficulty of landing under elementary conditions consist exclusively of "flattening out" at the right moment. Plainly, if a machine which weighs a ton hits the ground at a sharpish angle with a speed of 50 miles per hour, the undercarriage will be ripped off and the passengers will be jerked forward

very violently or even thrown out. On the other hand, if the nose of the machine is pulled up when the wheels are still 20 feet from the ground, the machine will drop to earth with a tremendous thump and the undercarriage will crumple up ; moreover, as forward impetus is not yet wholly lost, the machine will slide heavily along the ground on its stomach. To prevent these or lesser mishaps, the pupil must pull back the joystick sufficiently to flatten out the machine when the wheels are not more than 2 feet above the turf.

The instructor will take care that the "dual control" landings are correct. If the pupil tries to flatten out too late, a firm hand will do it for him ; if he attempts to pull back the stick when he is still 30 feet up, he will find the instructor has gripped it so tightly that it is immovable for the moment. Perseverance will soon bring proficiency. Confidence and determination are half the battle in what is unquestionably a nervous job. Generally speaking, if a pupil's first two or three landings are good he experiences no further trouble ; but a man who has commenced with a series of blunders may require as many as fifty practice landings before he is proficient.

The next stage in education consists of "taking off." The earlier aeroplanes required to be literally lugged off the ground ; modern types practically skim off automatically as soon as they have gathered speed, and there is not the least reason why a cautious man should not take any machine off and fly it straight on a calm day at the first time of asking ; turning and landing are the sole difficulties of flight under training conditions, when the atmosphere is safe and the machine substantial and stable. To take off, the machine is pointed up wind and accelerated. When the air-speed indicator registers the minimum flying speed of the aeroplane in use, or slightly more, the joystick is very gently pulled back a little and the machine floats off. The only chance of a blunder in getting off is to pull the joystick back a great deal too much, when the aeroplane would rear up, "stall," and fall back on to its tail.

MAKING A TURN

Turning comes second to landing in point of difficulty. It is always easier than landing because it is less dangerous, and the pupil is consequently less excited ; provided the turn is

made at a fair height, any mistake can be corrected without fear of a mishap. Further, there are many aeroplanes which practically "bank" themselves automatically to suit the movements of their rudders. The difficulty of turning during the early stages of flying arise from the fact that both the rudder and the joystick must be operated, whilst the degree of movement given to each of these controls depends upon the sharpness of the turn; moreover, the rudder action bears a set relation to the bank.

There are two separate ways of learning how to turn. The commonest is for the instructor to execute a large number of similar turns on a dual control machine, whilst the pupil keeps his feet and hands on the controls and his muscles become familiar with the movements. These turns will always be made along a curve of approximately the same radius; the machine will always be turned into the wind, and the wind will be of the same strength and direction in all such practices; and the speed of the machine will be constant. By this method the pupil rapidly acquires familiarity with a given sort of turn. The second step is for the pupil to execute similar turns until he can do them perfectly on demand. He then goes up alone and makes similar turns without an instructor on board. Finally he is sent up alone to a greater altitude and told to vary the radius and speed of his turns little by little until he gradually familiarises his muscles with the "feel" of every conceivable turn.

Other instructors adopt a very different method, which throws a greater strain on the pupil, but renders him proficient more rapidly. The tyro goes up in a dual control bus, and the instructor proceeds in the course of the first few flights to execute all the simpler types of turn, performing some of them perfectly and others execrably. On a perfectly judged turn the pupil will feel the machine swinging round smoothly. On the other hand, if the machine is canted or banked over too steeply it will sideslip "inwards," i.e. towards its lower wing-tip and towards the centre of the curve; the pupil will "feel" the slip and a cold wind will strike his inner cheek. On the other hand, if the machine is not banked over enough for a given turn it will sideslip outwards, and the pupil will again "feel" the skid and also the draught on his outer cheek. After experience of a few clumsily made turns, he will be able to judge whether the turn is going

to be smooth as soon as the machine begins to swing; and as his hands and feet are placed on the controls he will also feel exactly when and how the instructor corrects the error. The instructor will then climb up to a safer altitude and relinquish the controls to the pupil, who will now steer a number of turns on his own account. After a very short spell under this system a pupil is able to execute all ordinary turns quite neatly; even if his first setting of the controls for a turn is slightly incorrect, he remedies the mistake so quickly that the turn looks quite good from the ground.

Whichever instructional method is adopted, the learner must grasp the fact that the correct use of both rudder and ailerons is essential to a perfect turn. Attempting to turn an aeroplane by the rudder alone is exactly like trying to steer a racing motor-cycle round a sharp corner at 50 miles an hour without leaning the machine and body over; an outward sideslip results in both cases. Consequently a given amount of rudder demands a proportionate amount of "bank," which is given by pulling down the aileron on the outer wing-tip. Should too much bank be given the consequences are exactly similar to leaning a cycle sharply over whilst negotiating a corner at a slow speed; in both cases an inward skid occurs.

A moderately clumsy turn can always be corrected either by taking off a little rudder or a little bank. If the machine is skidding inwards on an overbanked turn, the skid may be stopped in two ways:

1. Take off some of the bank by moving the joystick gently in towards the centre; the bank will then suit the rudder and the skid will cease.

2. Alternatively give more rudder, so that the radius of the turn is shortened to suit the bank, which was previously excessive; the rudder will now suit the bank, and the skid will cease.

It is of course possible for an extremely wild and clumsy turn to throw the machine temporarily out of control. Side-skids on motor-cars and motor-cycles are dangerous because the culprit makes impact with something hard before he has a chance to correct his blunder. This does not apply in the air, provided the blunder is committed at a safe altitude. Imagine, for instance, that a beginner overbanks to an absurd

degree when trying one of his first solo turns at 1000 feet up. He makes no immediate attempt to correct it and the machine begins to slide earthwards with its planes practically vertical. The heavy nose will take the lead provided the pilot—

i. " Centralises his controls," i.e. puts his joystick in the centre and kicks his rudder straight.

ii. Switches off or throttles down his engine.

In actual practice the pilot would assist the machine to recover by banking hard in the opposite direction.

Elementary turns should always be made against the wind, and the air speed should be increased by putting the nose down a little immediately prior to the turn.

CHAPTER VI

THE FIRST SOLO FLIGHT

SOLO flights will not be made until the pupil has confidence in himself, and until that confidence is endorsed by the instructor. In peace and war alike there is always trouble when anybody is accidentally killed or seriously hurt; and the pupil may regard the instructor's suggestion of a solo as a deliberate testimonial to his ability. He would not be sent up if the instructor thought it unsafe.

Before the great day arrives the pupil will have mastered the elementary handling of his machine. He should further acquaint himself with any special peculiarities of the training machine in use, as such information may be useful if he gets excited during his first few solos and puts the machine in unexpected positions. For example, one type of "school bus" *cannot* be flattened out if it once gets into a dive at a really steep angle; the greatest duffer is safe on this machine unless he descends at an excessive angle. It is the instructor's business to teach his clients the peculiarities of the machine, both by word of mouth and by object lessons in the air.

For his first solo the pupil will use the machine in which he has been trained, and will occupy his usual seat. He will probably be sent up quite unexpectedly, perhaps just after he is in from a "dual control" flight in which he performed very creditably and increased his self-confidence. The day will be absolutely calm and the instructor will see that there are no other machines in the vicinity. He will be told exactly what to do, e.g. "Climb to 500 feet, make two circuits, and switch off for your landing glide from 100 feet exactly above the cricket field." (This will be a landing which he has repeatedly made in a wind of the same direction and strength.)

Before this flight is made the pupil will have been put through the usual drill of starting up the engine and signalling for the "all clear" (see p. 29), besides having watched

his instructor and fellow-pupils go through it many times. We will imagine that he is seated in the cockpit, and has just commenced the run along the ground into the wind. As school aerodromes are always of great area, and a solo flight will be started from the extreme edge, there is no hurry about taking off, and the pilot must not pull his stick back too soon or too far. For the moment he may concentrate on keeping the nose of the machine dead into the wind, and steering an absolutely steady course. As soon as the jolting caused by the ground ceases, and he knows that he is off, he will naturally be anxious to gain height, since height spells safety and everybody is nervous on the first solo. *This temptation must be sternly controlled.* Climbing too steeply spells a "stall," i.e. just such a stoppage as befalls a motor-car when it is put at a hill too steep for it to climb, with the difference that an aeroplane has no device which can hold it stationary when it stalls. Pulling the joystick too far back in the run along the ground may cause the machine to rear up and stall. Taking off should therefore be done quietly and steadily. When the machine clears the turf, the joystick may be eased forward again a trifle, which will increase the speed of flight but lower the rate of climb. Speed in flying spells safety, and the motoring maxim that beginners should go slowly does not apply. Whether the aeroplane is flying level or climbing, the indicator should show a higher figure than the known "minimum flying speed." This varies with the different makes of school bus, and is likely to vary much more after the war; but if the minimum flying speed is 45 m.p.h., the pupil should keep the machine at 50 or 55.

A turn must on no account be attempted low down. Aerodromes exist in which such lofty obstructions as forests or hills compel a turn to be made at 100 feet when the wind forces machines to take off in certain directions; such aerodromes are wholly unsuited for training purposes. Granting that most school machines are not easily thrown out of control by a bad turn, the tyro should not be subjected to the very faintest risk. In his first solo, he should fly in a straight line, climbing gently without cessation, until the machine is 500 feet up. Then he can bring her round, and if in his excitement he muddles his rudder or bank, the aeroplane will recover in 200 feet and he will have oceans of room in which to regain full control. In 999 cases out of every 1000 the

soloist will be quite depressed to find that his stipulated two circuits (or whatever the specified distance may be) are complete and that he is now under strict orders to terminate a fascinating experience.

Now comes an ugly moment. One is master of all one surveys, perfectly safe, thoroughly enjoying the novel sense of independent competence, and would like to go on circling the aerodrome for ever. But down below is the broad green patch, and one is under stringent orders to descend to it immediately. A sense of helplessness mingled with feelings of revolt usually steals over the beginner at this point, for the first single-handed landing feels no less alarming than premature. Wise instructors will protect the pupil against any real anxiety by exact stipulations, e.g. landing is only to be attempted from a start at a given height vertically above a specified landmark. Under such conditions the "approach" will necessarily be accurate, and the pupil has only to bear the onus of "flattening out" at the correct moment. It is very certain that he will not defer flattening out until too late and ram the ground heavily nose-first. Again, since school machines are specially fitted with very sturdy undercarriages it is not at all likely that the pupil will flatten out sufficiently high up to be dangerous. The prospects all make for safety.

Should any difficulty arise, it is invariably countered in one way. All modern machines are designed to glide automatically and safely when their engines are switched off or throttled down and the controls are "centralised," i.e. the joystick put in the middle position and the rudder bar at right angles to the fore-and-aft centre line of the machine. A machine may be severely skidded on a turn, but if the pilot shuts the throttle and centralises his controls, the aeroplane will of her own accord get into a perfectly safe glide. The most automatic machine naturally requires a certain drop in which to effect such a recovery, and the depth of drop varies with different makes; but school machines are designed to recover quickly.

Only two emergencies are in the least likely to arise in the first solo when once the machine has taken off properly. The first is a sideslip due to a badly made turn, and the second is an engine stoppage which spells a forced landing.

Avoid any dangers connected with a bad turn by rising to

a good height before attempting a turn. Secondly, make a rule of turning *fast* by pushing the joystick forwards a very little in addition to the side movement required for a turn. This puts the nose down, and renders it easier to get into a glide if incorrect banking should provoke a sideslip. Thirdly, apply the methods previously demonstrated by the instructor to correct an incipient sideslip. An aeroplane can skid inwards or outwards on a turn, and the side draught will always show which type of skid is commencing. For example, if the draught hits the pilot's outside cheek his machine is skidding outwards. The machine skids outwards because it is not banked enough. So an outward skid can always be corrected by steepening up the bank a trifle. Similarly, in inward skids the draught is felt on the cheek towards which the machine is turning; and the machine obviously skids inwards because it is banked too much, just as a cyclist would tumble towards the inside of a turn if he canted his machine inwards at 45 degrees when he was only riding at ten miles an hour. Therefore, in an inward skid the pilot should reduce the bank by moving his joystick in towards its central position. Alternatively, either type of skid can be cured by the rudder. The machine, for example, skids inwards because it is banked too steeply for the turn which is in progress; but this very steep bank would be correct for a sharper turn of shorter radius. So the skid will end if more rudder is applied, and the turn is increased in sharpness.

Thus there are three ways of recovering from a sideslip, viz.

1. Getting into a glide.
2. Altering the bank.
3. Altering the rudder.

In due course all three will be mastered; but the pupil must understand early in his career that the gliding recovery is only possible when the machine is at a certain height, which depends upon its design. So if a sideslip is provoked quite close to the ground, the machine must be levered out of the skid by the rudder or the ailerons. The instructor should demonstrate all three methods, and they should be practised on a dual control machine under tutelage before a pilot makes any solitary experiments.

A forced landing is practically unknown on early solo flights, which are so brief that the good behaviour of the

engine can almost be guaranteed. In any case, a forced landing at this stage is only a practice landing under another name, provided the pilot obeys rules and the instructor knows his job. Young pilots hate flying round and round above the aerodrome, for they fail to realise that it assures them a big landing surface to steer for and plenty of room to run off their landing impetus. Forced landings from such regions of the air as an obedient pilot can visit in his early solo flights are not difficult. If the engine should fail immediately after the machine has taken off, it is simply glided back on to the turf and landed in the ordinary way, seeing that its nose is up wind.

In ensuing solo flights the pupil will gradually gain experience, usually as the result of getting into minor difficulties. He will come to know the effects of taking off at too low a speed, or with too much elevator—not because he has smashed a bus by such blunders, but because he has felt his controls " turn sloppy " or his tail commence to fly up alarmingly. He will know a good deal about sideslips, and will confidently be adding a few more degrees to his rudder and bank, i.e. begin to indulge in more daring corner work. His normal landings will be more accurate, and he will possibly have experienced at least one real landing scare, either through doing something beyond his powers or through an error of judgment. He will be able to hold his machine on a level keel and a straight course, and therefore will make merry at the expense of beginners a week or so junior to himself. For the moment he requires nothing but practice. Probably his introduction to the second stage of flying will not be by way of a livelier machine or immense altitudes or aerial acrobatics; he will simply be sent up when there are plenty of other machines about and when the air is not so calm as during his preliminary essays. These two novelties will keep him anxious for several hours. So far as " crowded air " is concerned, it is extraordinary how one other machine at the same atmospheric level can worry a young pilot, when both can do 80 m.p.h. and are limited to flying in rings round a common centre. Fortunately the rule of the air is very simple—keep to the right when meeting, and when overhauling another machine give it a very wide berth indeed, as its unconscious pilot may suddenly do a stunt turn right about. If two machines are flying in converging paths the

left-hand plane must give way. Generally speaking, other machines should be kept clear of; it is never possible to estimate what another pilot may be about to do, and the "wash" of a big propeller and wide wing-span can give the tyro a bump which will frighten him.

Pilots under training will not be sent in winds of appreciable strength, but quite a mild breeze is very instructive both in making turns and in landing; their general effect is to impress the pilot with the importance of several facts which he has already learnt. Before long he will be sent up on a "bumpy" day, when invisible air currents suddenly bank the machine over in disconcerting fashion. There is no more danger in a mild "bump" than when the machine droops a wing during the first dual control flight owing to the beginner mishandling his ailerons; and the correction is similar in both cases. The young pilot will not be trusted up when the bumps at low altitudes are genuinely severe.

CHAPTER VII

HOW TO LAND

It has already been hinted that landing is the most difficult part of flying. To impress on the tyro the absolute need of practising until the art of landing is mastered, let it be added that landing is also the most dangerous and the most expensive part of flying. While accidents in training have been reduced until under service conditions only one pupil is killed for every 120,000 miles flown, the majority of accidents still occur through the pilot's inability to land. When peace returns, commercial employers will have no jobs to offer pilots who sometimes land clumsily under favourable conditions, for the life of an aeroplane will depend principally on whether it is usually landed perfectly or not. An aeroplane is a very flimsy structure at the best of times. It may weigh anything from one to eight tons, and heavier machines still are being developed. The average landing speed of modern machines is still on the high side of forty-five miles an hour. A heavy weight, moving at railway speeds, cannot be brought into contact with the hard earth painlessly. The shock absorbers fitted to the under-carriage cannot absorb unlimited strains. An aeroplane soon becomes loose and "soggy" in all its joints if its pilot habitually thumps it down on the ground from twelve inches higher up than is necessary. Bad landings will make themselves felt in terms of £ s. d. upon balance sheets, and the responsible pilots will be black-listed. From the three standpoints of technical efficiency, personal safety, and economy, every pilot must practise landing until he is supremely deft under all ordinary conditions.

This chapter deals with landing from all ordinary points of view, commencing with the elementary types and proceeding to more advanced and difficult tactics.

It is difficult to fix a point in the air at which the "descent"

merges into the "landing," but for the purpose of analysis the landing may be said to consist of the final glide to earth from a height of 100 feet. In judging a landing, the pilot may be said to select a mark on the ground. He decides that from an invisible spot in the air, 100 feet above the selected mark, the natural glide of his machine will bring him to earth at the desired point on the landing ground. Having selected this point, he descends to it by any of the recognised modes of "coming down." He now has a closer view of the proposed final glide: it may turn out that he selected his "point" accurately, or he may find that a glide will terminate on a most undesirable spot. Circumstances which need not be described here will govern his decision: he may circle round and choose another point, or he may have to make the best of his blunder.

Supposing that the selected "point" is well judged, he has only two things to do, viz. to glide at the correct angle and to flatten out at the correct moment. A word must be said on each point.

GLIDING DOWN TO LAND

Landing consists of an impact with the ground, and it is the pilot's business to make that impact as gentle as possible. The more slowly the machine lands the gentler will be the impact. Therefore the glide must be slow. Unfortunately aeroplanes will not support themselves in the air or remain under control at really slow gliding speeds; 45 m.p.h. is below the average minimum, though the figure will be vastly reduced some day. Before flying a machine, the pilot is told its minimum flying speed, below which the machine will stall. Landing must be performed at or above this speed; as a "stall" near the ground is highly dangerous, the wise pilot will glide at a mile or two more than the minimum. As he approaches earth on a machine with a minimum speed of 45 m.p.h., he will keep a wary eye on his indicator and handle his joystick to keep the speed to say 48 m.p.h. If the needle drops to 44 m.p.h., he will put the nose of the machine down, and the steepened angle will send the speed up again.

FLATTENING OUT

The gliding angle may be 1 in 7 or thereabouts. It is plain that a ton weight, striking the earth at this angle, and at a

speed of 50 m.p.h., will create a frightful impact. So, just before the under-carriage wheels touch the earth, the pilot pulls his joystick back a little, gently, and levers the nose of the machine up. This acts as a brake—you cannot climb a hill on a motor-cycle when the throttle is only just open far enough to keep the machine moving on the level. In a 45 m.p.h. glide our imaginary machine is barely moving, and it cannot climb invisible hills without more power. So it does not climb ; it puts its nose up a little, drops its tail down a little, and "stops" or "stalls," i.e. its pace sinks to 40 m.p.h., at which it cannot support itself in the air. So it loses height vertically, whilst continuing to glide forwards at decreasing speeds under the impetus of its glide. If all this occurs twelve inches above the turf a very good landing has

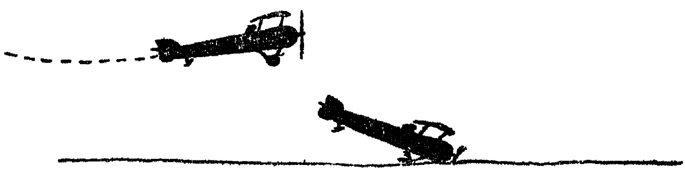


FIG. 27. A bad "pancake" landing.

The aeroplane drops almost vertically, with sufficient forward "way" on it to buckle the undercarriage. If executed from a lesser height, and with less forward "way," this type of landing is useful in confined spaces, where a quick stop is essential.

been made ; but if the flattening occurred 10 feet up, the fall is heavy. A "pancake" landing of this type will strain the aeroplane and shake up the pilot, even if the entire under-carriage is not ripped off backwards at impact, causing the machine to collapse on its nose, slide forward, and wreck itself.

Thus, after the "point" 100 feet up has been selected, the next essentials of a good landing are a glide at a fraction over minimum speed, culminating in flattening out at precisely the right moment. Practice in all three items is essential, and should be continued until perfection is reached.

The effects of wind on the landing may now be considered. A machine can be landed up wind, down wind, or across the wind.

LANDING UP WIND

The assistance which wind can give may be judged by the fact that the gentlest landings are possible in the teeth of a

strong, steady wind. The minimum flying speed of an aeroplane is speed through the air, not speed across the ground. A minimum speed of 45 m.p.h. in the air will also be a speed of 45 m.p.h. across the ground on a windless day. But if a wind of 10 m.p.h. is blowing from the east, the machine's minimum speed across the ground is 35 m.p.h. when it is flying east and 55 m.p.h. when it is flying west. Landing up wind it could touch ground at 35 m.p.h., but landing down wind it would "stall" in the glide unless it descended at not less than 55 m.p.h. Moreover, after landing down wind, it would require a much longer run before coming to rest, and therefore a bigger field. Up wind landings are therefore the rule, in the double interests of a gentle impact and a short run. It is folly to land in any other way, except under

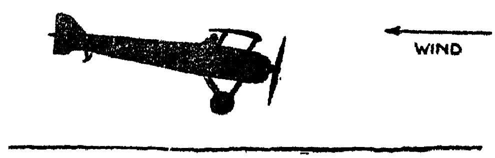


FIG. 28. Landing up wind.
Minimum air speed of machine, 45 miles per hour; wind blowing at 10 miles per hour; ground speed in up wind landing, 35 miles per hour.

compulsion. For this reason every aerodrome hoists a prominent wind direction signal, usually consisting of a long cone-shaped bag, with an open mouth, tied to the top of a flagstaff. In landing away from aerodromes, the pilot can judge the wind direction by watching the smoke trails from chimneys; the slipstream of his propeller or the wind stirred by his flight prevent him from judging the breeze by mere sensation. At night aerodromes arrange their landing lights as wind signals, see p. 134. In landing away from aerodromes in the dark it is possible to detect a good breeze by noticing the behaviour of the machine whilst flying at various angles across a row of lights. If these lights remain in view throughout the descent it should be possible to land up wind.

LANDING DOWN WIND

Landing down wind upon a large aerodrome is easy enough, but implies touching earth at a higher ground speed, and is

therefore bad for the machine. Moreover, as the glide is faster, flattening out has to be more exactly timed than in landing up wind. In landing with the wind astern the main point is to keep the speed up. Being accustomed to landing up wind at a low ground speed, the pilot is apt to be disturbed as he nears the ground and sees it rushing under him so fast; he takes his eyes off the indicator and reduces his gliding angle. The result is that though he is crossing the ground much faster than usual, he is passing through the air much too slowly; the machine stalls, and a ton cannot be dropped even 20 feet with impunity.

At the same time down-wind landings are occasionally very risky. One such tempting but perilous example should be grasped even by novices. Imagine that a pupil takes off up wind across the aerodrome on one of his earlier solo flights.

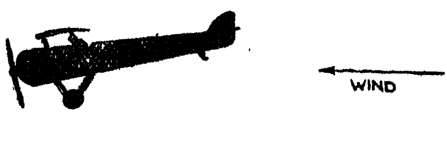


FIG. 29. Landing down wind.

Minimum air speed of machine, 45 miles per hour; wind blowing at 10 miles per hour; ground speed in down wind landing, 55 miles per hour.

Allowing for the preliminary run and the probable size of the aerodrome, he is perhaps 100 feet up when he passes the further boundary of the aerodrome. Being a sensible man, he intends to head on dead into the wind until he is several hundred feet up, and can safely make a somewhat timid turn and commence circling round the drome. As he crosses the aerodrome boundary his engine misfires and stops. He is only 100 feet up and is flying up wind. To make an up-wind landing on the aerodrome he has to make a complete circle, not to speak of getting over to a point in the air above that part of the aerodrome from which he started, which is now immediately behind him. The feat may just be possible, but a novice has no earthly chance of performing it. The machine will lose a great deal of height in turning through a complete circle, and it was only 100 feet up when the engine stopped, some of which will be lost before the pilot's mind is

made up. He is not very expert in banking, and when he finds his machine canted sharply over at no great distance from the ground he may lose his head. Instructors have often committed blunders under such circumstances. It is folly for a pilot to attempt a circular turn followed by up-wind landing on the aerodrome under such circumstances. There are two alternatives, the second of which is infinitely wiser. The first is to make a turn through half a circle, and perform a down-wind landing on the aerodrome. This may just be possible under the conditions stated. Alternatively—and this will depend on the nature of the wind and the ground—the pilot can put the nose down and glide on in the original starting line to make a forced landing up wind outside the aerodrome. Whether he would do this in practice would depend partly

FIG. 30. One of the commonest accidents.

The engine fails just as the machine is crossing the boundary of the aerodrome after taking off. If the pilot tries to turn back down wind, he will almost certainly stall and crash. He should glide on into the wind, no matter what the ground outside the aerodrome is like.

on his height, on which the safety of attempting a turn principally depends: partly on the ground in front of him, for while it is not nice to land on houses or trees, no great harm is normally done by a slow up-wind landing in a field so small that the machine gently charges a hedge; and partly on the strength of the wind. If the wind is blowing at 5 m.p.h. there is no great difference between landing up or down wind, except that a slightly faster glide and longer run result from landing down wind; but with the wind blowing at 25 m.p.h. the speed of a down-wind glide and length of the subsequent run approach the formidable.

LANDING CROSS WIND

Three separate speeds enter into a landing across the wind. The machine is gliding forwards at say 50 m.p.h. air speed.

She is moving at say 40 m.p.h. with relation to the ground. She is also "drifting sideways."

Taking an extreme instance to make this point clear, let us picture a machine with a minimum air speed of 45 m.p.h.

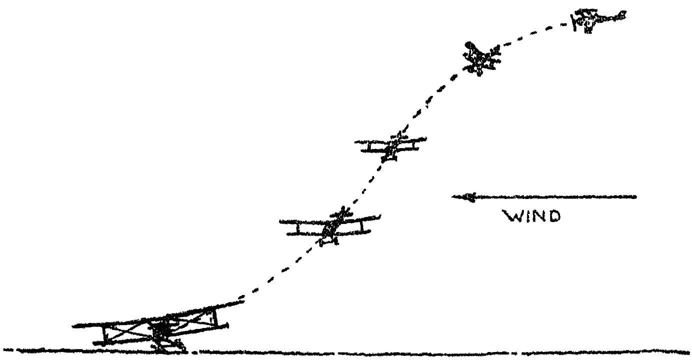


FIG. 31. A landing across the wind.
Resulting in a crashed undercarriage. Cp. Fig. 32.

landing at right angles to a wind blowing at 45 m.p.h. So long as the machine is off the ground, the main effect of these opposed forces is that the machine drifts sideways. The instant her wheels touch ground the immovable earth offers a gigantic resistance. The ton weight of the aeroplane is

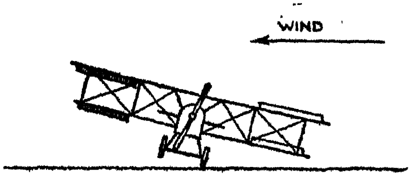


FIG. 32. The proper way to land across the wind.
The aeroplane is made to sideslip into the wind, and lands on one wheel.

pointing in one direction. The strong wind is pushing at right angles. The ground is attempting to grip the wheels by friction. Something must go. The under-carriage is torn off, the machine collapses over on to that wing-tip which is remote from the wind, and a tremendous crash results.

Landing across the wind is often done by good pilots by

using the ailerons to hold down the wing on the side from which the wind is blowing. The machine then "sideslips into the wind," touches earth with the windward wheel first, and runs fairly straight after alighting. The manœuvre needs careful timing, and should not be attempted until the pupil is really expert in elementary flying and he has seen his teachers demonstrate the stunt.

ALIGHTING

The aeroplane can alight safely in three different ways. It may touch ground first with its wheels, or with its wheels and tailskid simultaneously, or with its tailskid first and its wheels afterwards.

1. *Wheels first.*

Such a landing cannot imply a very steep angle of descent, as low under-carriages are used to reduce wind resistance,

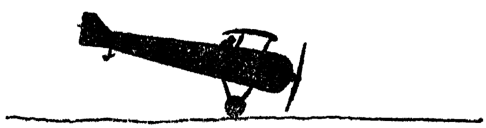


FIG. 33. "Wheels-first" landing.

and the propeller would hit the ground first if the gliding angle were really steep. At the same time, if the tip of the tailskid were far off the ground when the wheels first touched, a very nasty shock would be experienced and a crash might result. In most landings the wheels touch earth appreciably before the tailskid lands, and such a landing may be very nearly perfect; indeed, only the fact that "flattening out" has been performed a second too late may distinguish it from the "three point" landing described below. On the other hand, a "wheels-first" landing may be made at such a steep angle that the propeller narrowly misses fouling the ground, in which case the tailskid is still high above ground when the wheels touch. The results will vary with the angle and with different machines. The under-carriage may fold backwards; the machine may bounce; the pilot may use the joystick to flatten out rather too late, and the aeroplane may shoot upwards, stall, and drop heavily. It is clear that if a pilot habitually receives, first, a bad jolt as his wheels touch,

and then a second jolt as his tailskid flops to earth, he is flattening out too late.

2. *Wheels and Tailskid land simultaneously.*

With most types of machine this represents the perfect landing, and is easier to describe than to effect. The shock

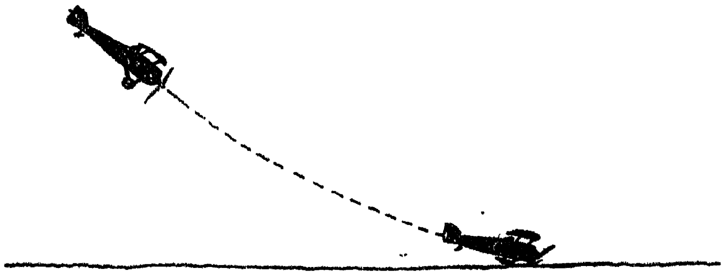


FIG. 34. A bad landing.
The pilot has dived at too steep an angle, and attempts to flatten out too late.

is reduced to infinitesimal proportions. Flattening out has been executed at precisely the right height and moment. If flattening out is done too late, the wheels land first; if too early, the tailskid lands first with somewhat of a thump; if *very* much too early, the machine pancakes from such a height

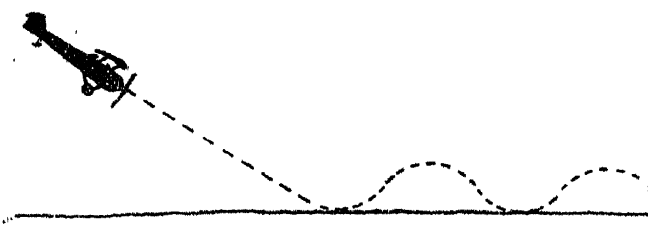


FIG. 35. A "bounce" landing.
The pilot has dived too steeply.

that the heavy nose has time to lever the tail up again, and this implies such an appallingly heavy pancake that the under-carriage is bound to collapse. A three-point landing is achieved by flattening out so that the machine simultaneously loses flying speed and straightens out its longitudinal axis parallel to the ground at a height of not more than 3 feet,

if this height is 6 inches so much the better ; if it is 1 foot the landing is one that no pilot need be ashamed of.

3. *Tail first.*

When the tailskid is the first part of the aeroplane to touch ground, one of three things has happened. When a novice makes such a landing, he is generally afraid of flattening out

Fig. 36. A "balloon" landing.

The stick has been pulled back too far in the attempt to flatten out. If the speed is high the machine will take off again. If the speed is low it will "stall" at the end of the dotted line.

too late and ramming the ground with his under-carriage ; consequently he flattens out when the machine is say 10 feet up. He pulls the nose up by pulling the joystick back, the machine pancakes, and the tailskid lands first. Or, again, much the same effect may be produced by pulling the joystick back too far in flattening out several feet up. The nose of the machine is forced up and the aeroplane "balloons" instead

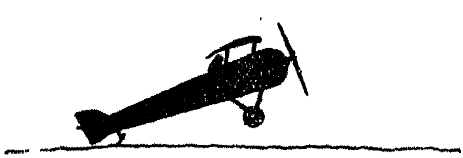


Fig. 37. "Tail-first" landing.

of flattening out. What might have been a smooth landing is spoilt ; a too abrupt stall results, and the tail comes down heavily. At the other extreme, a "tailskid first" landing is the cross-country flier's standby. Perhaps he loses himself. Perhaps his engine has stopped. At any rate, he is compelled to land away from an aerodrome. He selects a field which looks promising from the altitude at which he first

noticed it. On closer acquaintance, he perceives that it is too small for the machine to run off its impetus before colliding with a fence, or that a previously unseen ridge or ditch halves the useful area of the field ; or that what looked like smooth turf is really deep hay, which will scotch his wheels and force the machine to turn a somersault if a normal landing is attempted. The machine has to be landed with little or no " run " on her. A pancake landing is the only hope. He flattens out 10 feet or more above the ground, according to the make of his machine, the size of the landing ground, and the nature of the surface. The drop of 10 feet or more after flying speed is lost absorbs most of the forward impetus, and the plane lands " like a poached egg."

Forced landings are dealt with under the heading of Cross-country Flying on p. 109, and Night Landings on p. 133.

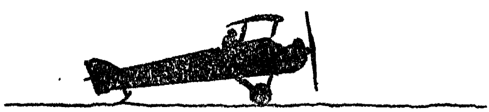


Fig. 38. " Three point " landing.

CHAPTER VIII

MAKING PROGRESS

WHEN the pupil has made such progress that flights round the aerodrome in good weather and at modest altitudes can neither educate nor interest him he is set harder tasks. Promotion will commence with flights in perceptible winds and in bumpy weather, though he will continue to hug the neighbourhood of the aerodrome. Wind will make no particular difference, except that it will impress on him the need of keeping his feet pressed quite firmly on the rudder when taxying, and accustom him to seeing his machine point its nose slightly off the line on which he is travelling. He may also have a few narrow escapes of a "stall" when turning; to quote an extreme instance, a machine with a minimum flying speed of 50 m.p.h. is flying into the teeth of a 30 m.p.h. wind, and thus has a speed over the ground of only 20 m.p.h. The machine then turns through half a circle to fly down wind. After completing the half turn its minimum air-speed is still 50 m.p.h., but down wind this represents a speed across the ground of 80 m.p.h. A clumsy turn under these conditions may provoke a stall. The pilot will feel his controls "going flabby," and must put the nose down to gain speed; a few frights of this kind will do him good.

Before long he will be told to climb much higher than he has ever been before, for which feat the instructor is sure to select a clear day. The tyro should observe three precautions, viz.: (i) To keep a careful eye on the weather; he is not yet qualified to fly in mist, clouds, or thunderstorms. (ii) To descend if he is conscious of palpitations, or drumming in his ears. (iii) To descend slowly; it is very tempting to swoop down in a tremendous rush, but rapid variations of air pressure are not healthy, and skill is needed to come out of a fast dive with safety.

The higher the machine climbs the steadier will the air

feel, unless abnormal conditions are encountered. The novice will not be exposed to really bad bumps in any case, and mild bumps have little more effect on the machine than the uncertain control work of a first soloist, and are corrected in the same way.

The first long descent will be interesting, and is quite likely to be misjudged, i.e. the machine will not find itself at the selected spot, 100 feet up, from which the anticipated glide into the aerodrome was to have been made. For this reason the engine must be kept running during the descent, so that part of a flat circuit may be made two or three hundred feet up in order to facilitate the final landing glide. The pilot will be aware that some engines require humouring during long descents (see page 102), or they evince a bad habit of refusing to open up on demand. Such defects may be due either to cold or to fouling of the sparking plugs. The former propensity is met by interlarding the descent with occasional flat circuits, and the latter should receive similar treatment from a pilot who is too inexpert to dive with his engine on or to try an occasional "zoom."

Should the engine be stopped accidentally, the concluding portion of the descent will require very accurate judgment, as a landing with engine off leaves little room for blunders. It is possible under certain conditions to restart a willing engine by a fast dive, leaving the wind to "swing the prop," but this is beyond a beginner's compass, and great care should be taken not to "lose the prop," as an accidental engine stoppage is termed.

The bulk of the descent will be made in a wide, flattish spiral. Steep spirals of short diameter should be avoided at this stage. The sideslip meter should be watched. The best type is very simple, and consists of a bit of wool or ribbon tied to the forepart of the centre section. In a perfectly banked turn, this trails backwards along the fore and aft centre line of the machine. If the turn is overbanked and the machine sideslips inwards the ribbon will trail towards the outside of the turn, and the pilot will feel a cold draught on his inside cheek and vice versa.

Throughout his first high flight the pupil has the satisfaction of knowing that he is much safer than in his earlier essays at low levels. Given plenty of altitude, a machine will extricate itself or can be extricated from any difficulty.

In conclusion, the flier must be careful not to lose himself. As visibility is assured for several miles from a height of only 5000 feet, he is not likely to fly too far afield in climbing to 10,000. But he should keep a wary outlook for drifting

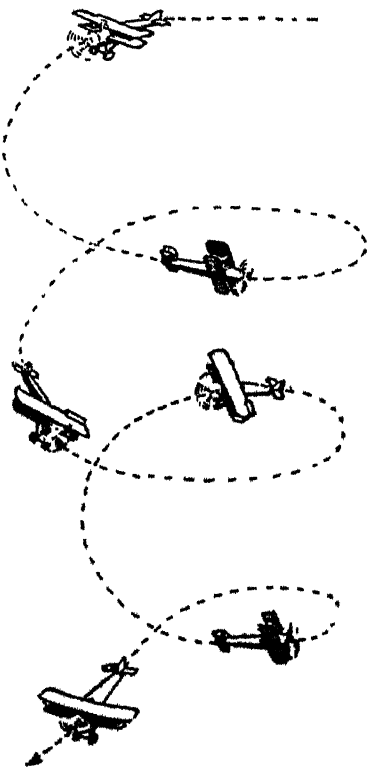


FIG. 39. Descending in a spiral.
The pilot comes down on to a piece of ground vertically beneath him, and can study the ground as he descends.

clouds, sea frets, and other sudden reductions of visibility. Skilled pilots dread such conditions, and the novice will reflect that his experience of forced landings is *nil*.

Cross-country journeys and "stunting" are dealt with in later chapters.

At the stage when confidence begins to come with a sudden rush, most pilots require steadying rather than encouragement. Flying on a good machine in favourable weather seems quite absurdly simple after short experience. The beginner should realise that the air is an extremely tricky medium in which to practise locomotion, and that the penalties of recklessness or of an appreciable blunder are likely to be severe. Self-restraint, caution, and incessant practice should compose the aspirant's motto. Premature daring is often a euphemism for suicide.

CHAPTER IX

HOW TO HANDLE THE ENGINE

CHAPTER III deals with the maintenance and repair of the engine from a ground standpoint, and will be of service to pilots who take an intelligent all-round interest in their power units. Some of the finest pilots are fundamentally unmechanical, and though such men may be unfitted for commercial jobs in peace time, they will certainly figure among those who take up flying as a hobby or in the Royal Air Force. A pilot who makes no pretence of being an engineer, and is bored by technical information, must nevertheless study his engine from a flying standpoint if he wishes to excel, while a moderate sympathy with his engine will occasionally prevent nasty accidents.

In the first place, no sane pilot taxies out for the short run which precedes "taking off" without satisfying himself that his engine is fit for flight. The most stringent series of checks conducted by the ground staff is not an absolute safeguard. A single combination of an inefficient mechanic and a flurried foreman may lead to an engine choking and stopping just as the machine leaves the aerodrome, which invariably puts the pilot in a very awkward predicament, as he cannot safely turn back to land on the drome, and the ground immediately in front of him may be quite unsuitable for an emergency landing. Consequently no pilot should signal for the mechanic to stand clear and the chocks to be withdrawn before he has absolutely satisfied himself that his engine is in perfect order. This implies the following tests:

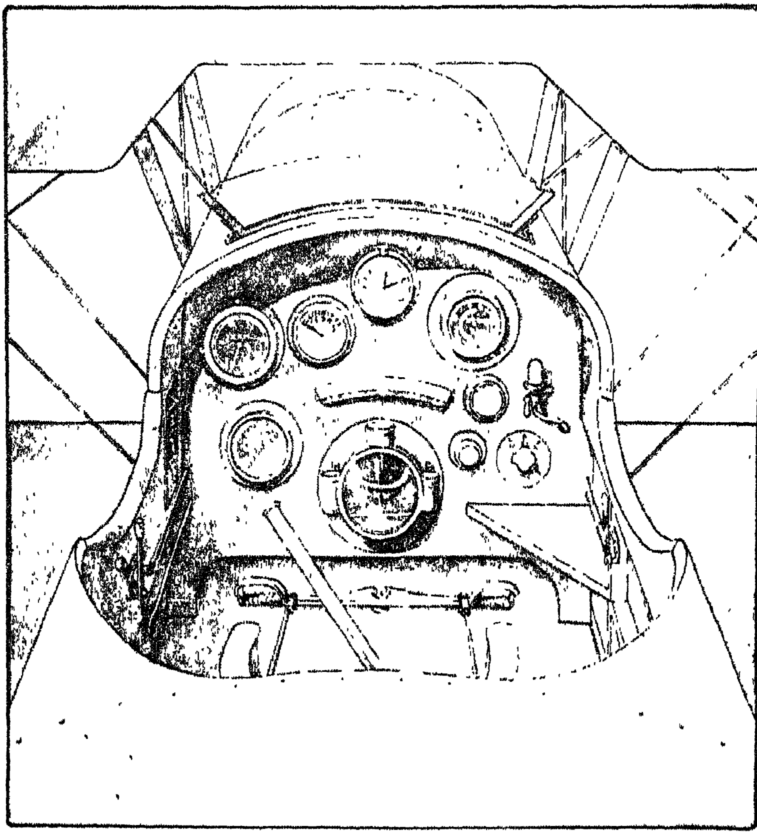
First, the oil must be circulating freely at the proper pressure; if it is not, an engine failure may occur about 100 feet up with the machine heading out for the open country. If the mechanics have already warmed the engine up, the pilot will make his test before entering the cockpit by placing a hand on some part of the engine remote from the pressure

pump, e.g. whichever end of the overhead valve gear is most distant from the oil-feed pipe. If this is hot, oil is evidently travelling right round the engine. On entering the cockpit, a glance at the gauge will show what pressure is recorded; the pressure should be steady at the figure stipulated for the type of engine in use, e.g. 20 lbs. per square inch. If the figure is higher, either a pipe is choked or else the cold oil is building up a resistance in the pipes. If the figure is below the normal pressure there is a leak somewhere. If no pressure is registered, either the pump is broken or else there is a very bad leak indeed. To attempt a flight under any of these abnormal conditions is suicidal. Excessive pressure would result in a burst pipe or a "seized" bearing; insufficient pressure means that the engine will stop in a few minutes, and may quite probably wreck itself. As quite a small aero engine costs £500, whilst large ones are priced at upwards of £3000, these routine matters have their financial side.

With a rotary engine and with some types of radial engines the oil is merely pumped into a selected part of the engine, and either slung about inside the engine by centrifugal force or splashed about by the rapidly moving cranks. In such cases no pressure is stipulated and no gauge is fitted; the oil pump merely delivers a constant flow of oil. The oil-indicator on a rotary engine usually takes the form of a "pulsometer," in which a cushion of air is imprisoned between the top of a column of oil and a dome of clear glass. At each stroke of the pump this cushion of air is further compressed and the tip of the oil column heaves upwards and sinks again. With such a system a glance at the pulsometer supplies all necessary information. A radial engine may be fitted with a simple indicator showing whether the pump is working and whether oil is passing.

Secondly, as soon as the pilot is assured that the lubrication is in order he must proceed to test all the ignition systems (there are usually two), to test the carburation, and to see if the engine will run up to its proper speed. None of these tests can precede the oil test, for an engine cannot safely be accelerated unless the oiling is perfect. These three tests are carried out more or less simultaneously.

The first acceleration must be *gradual*. A fighting pilot may bang his throttle lever open and shut, as if it were a door and he were in a temper, but such violent changes of load



A TYPICAL COCKPIT, OR "OFFICE."

Showing Control Stick, Rudder Bar, and Instrument Board.

Clock.

Tachometer. Air Gauge. Altimeter.

Inclinometer. Petrol Gauge. Oil Pulsometer.

Air Speed Indicator. Compass. Hand Pump. Ignition Switch.

On left-hand side of Cockpit { *Front*—Electric Light Switches. *Rear*—Carburettor Levers.

On right-hand side of Cockpit { Ignition Lever.

To face page 97.

and speed rack an engine terribly, and are avoided by all sensible men in ordinary flight ; they are specially unpardonable with rotary engines, in which a very heavy weight is spinning at great speed when the throttle is wide open. The proper procedure, after completing the oil test, is to open the throttle gradually and advance the ignition a little at a time simultaneously. This method imposes the extra stresses imperceptibly, and further gives time for the oil pump to force an additional supply into all the bearings. In the course of a minute or so, the needle of the revolution counter advances to the specified figure for maximum revolutions. In this connection the pilot should master the revolution limits of his engine. Many modern engines cannot safely be run at full speed until they have climbed up into the reduced atmospheric pressures at 10,000 feet and over. The maximum figure for a ground test is often 100 r.p.m. below the figure permitted for brief spurts in actual flight, and the maximum r.p.m. for a ground test may be 300 r.p.m. below the maximum for a spurt at great altitudes. The specified limits must be learnt by heart.

While the engine is being opened out, the pilot will have a chance to study the carburation. If the engine "picks up badly," i.e. if its beat becomes uneven and it chokes or coughs during acceleration, it is unfit for immediate flight, and the mechanics should be ordered to put it right. It may be that the engine is merely too cool and will be correct when it has reached the temperature for which the carburettor is adjusted. It may be that there is an obstruction somewhere, or a bad air leak in one of the inlet pipe joints. The pilot or slow-running jet usually has a marked influence on the "pick-up," and a speck of dirt in one of its fine passages will spoil the acceleration.

If the revolutions and pick-up are satisfactory, the pilot will next test each ignition separately by switching off all the others. When set to run on one ignition, the beat of the engine should remain absolutely even, but the revolution counter may show a slight loss of engine speed. Flight should not be attempted until both ignitions are functioning perfectly.

During the above tests the pilot will keep a watchful eye on the exhaust gases and on the water-cooling radiator (if

any). Blue smoke in the exhaust means over-oiling, black smoke means that the gas is too rich in petrol. There is no harm in starting with the water very hot, as overcooling is commoner in the air than overheating; but the water must not boil. During the ground tests the radiator blinds or shutters should be kept wide open; otherwise the water will boil before the oil becomes really fluid.

If any device for correcting the carburettor mixture at altitudes is fitted, it should not be tested by inexperienced persons at ground level. The use of such devices at or near sea level usually has the effect of generating intense heat, which may easily damage the engine, and in extreme cases might even set fire to the aeroplane. They should be adjusted and overhauled only by experts.

When satisfied that the engine is running well, the pilot may proceed to take off, and will of course use his engine in taxying into position for his run up into the wind. Little need be said on this point, as "rolling" will have constituted his first lessons on the machine, and he will have learnt any peculiarities in its taxying methods, which are usually concerned more with the aeroplane than with the engine. It should, however, be remembered in taxying a twin-engined machine that a good deal of steering can be performed by throttling down one engine and opening up the engine remote from the side towards which it is desired to turn. In taxying many types of aeroplane the engine should be slowed down after completing a turn, as the machine may continue to swing when the controls are centralised.

In the run up, the handling of the engine will depend on the size of the aerodrome. If there is not much room for a start, the least hint of sulkiness on the part of the engine will influence a wise pilot to pull up and repeat his tests before he takes off. On the other hand, if he has plenty of room to spare, he can play with his levers as he gathers speed. In any case he should get his levers set as soon as possible for the speed at which he intends to take off and then leave them severely alone until he has obtained a fair height. Petrol engines are kittle cattle, especially when their oil-tanks are not hot, and any jockeying with the throttle or ignition may induce a fit of sulks. This especially applies to rotary engines, which have a floatless type of carburettor. Their gas mixture is governed by (1) a so-called throttle, which both

controls a tapered needle sliding in a horizontal jet and also moves a shutter sliding across the air intake; and (2) by a "fine adjustment valve," which determines the petrol pressure behind the jet. Each of these controls is operated by a separate lever, and the two levers work side by side on a quadrant. Until their settings are mastered it is not difficult for a novice to upset the mixture by misplacing them in relation with each other; and fiddling with the levers late in the run up or just after taking off may provoke the awkward predicament described on page 85. Generally speaking, the juvenile pilot will be well advised to gain the necessary taking-off speed in his run up, and then leave the engine controls severely alone until he has (1) gained a safe height, say at least 500 feet, and (2) swung round so that he can glide into the aerodrome if his engine sulks. Remember that a turn at low altitude with the engine off is one of the most dangerous situations flight can provide.

When the machine is well aloft, engine failures can be viewed with comparative equanimity by any pilot who is confident in his powers of making an emergency landing. Maintaining a reasonable altitude, regarding 1000 feet as the minimum and 3000 feet as the normal, is a real insurance against danger, for such heights confer a wide choice of landing grounds. The pilot has three chief assistants in keeping a check on the behaviour of his engine. His revolution counter, or tachometer, comes easily first, with his ears and nose second and third. A brief acquaintance with a given make of engine will instruct a pilot as to the revolution speed it should register with the engine controls and aeroplane controls in given positions. The force and direction of the wind and the inclination of the aeroplane in relation to the ground affect these inferences to some extent; but the revolution counter is an infallible guide provided the pilot is flying on a steady course with his controls remaining in a given setting. If the engine speed slows under such conditions something is amiss. Then the ear supplements the message of the revolution counter by noticing an interruption in the thunderous rhythm of the exhaust—obviously, one or more cylinders are missing fire; perhaps a valve has gone wrong, or a sparking plug has sooted. Possibly the rhythm remains unbroken, in which case the nose will probably discover that the engine is emitting an unusually hot

and oily smell. What should the pilot do under such circumstances?

In a flight over enemy country he can of course do nothing but say his prayers and obey orders, which may imply trying to finish his job at all costs, or alternatively, putting his nose down and trying to reach home in as flat a glide as is possible, whilst hoping that the engine may change its mind. In peace flying he must give weight to more sordid considerations. If one cylinder is misfiring, as indicated by the broken rhythm of the exhaust, he can probably continue his flight, though the speed will fall off; but the engine is thrown out of balance, continued flight will cause unpleasant vibration, and the errant cylinder may provoke consequential damages. He should land at the first satisfactory opportunity. On the other hand, a drop in revolutions accompanied by over-heating is far more serious. It is just possible that his radiator is boiling as the result of fast, prolonged climbing in a very hot sun; in this case the engine will cool down if it is given a short rest by a spell of horizontal flight at cruising speed, or by a glide with engine off or throttled well down. Still, it is never safe to jump to this conclusion. The cooling water may have leaked away. The oil may have leaked away. A speck of dirt may have choked an oilway and one of the bearings may consequently be on the verge of "seizing." These and other similar troubles occasionally wreck the entire engine. If the least doubt exists as to the cause of the loss of speed, an immediate descent is indicated; and the same conclusion is usually inevitable when the cause is identifiable. During such an enforced descent the engine should preferably be switched off; but an inexperienced pilot will often risk a descent with the engine throttled right down, as he may misjudge his landing, and the use of the engine may serve to avert a mild crash.

This brings us to the question of whether it is best to land with the engine "on" or "off." This will always be a debatable matter as long as petrol engines form the power units of aeroplanes. On the one hand, an "engine-on" landing always leave room for second thoughts. If the selected ground or the gliding approach prove disappointing the pilot who has kept his engine running can open his throttle at the fifty-ninth minute of the eleventh hour, circle round, and try another field or a different glide. In some cases the pre-

caution of keeping the engine running will avert a crash which would otherwise have been inevitable. On the other hand, the fact that the engine is running occasionally converts a landing which might have been a subject for laughter into a tragedy. A slight error of judgment at the last moment produces a collapse of the under-carriage. An ignition wire is ripped off its sparking plug and spits a hot spark into some petrol spilt on the ground from a safety overflow pipe or from a tank perforated by a displaced strut. In an instant the wreckage flares up. Between Scylla and Charybdis it is difficult to steer. A half compromise is possible. The engine should certainly be kept running until a pilot is tolerably expert in judging his landings. After all, misjudged landings are far commoner than conflagrations, and expert pilots habitually keep their engines running with a view to taxying the machine towards the hangar, though this is quixotic, as a warm engine can easily be restarted after the landing has been made. When a proper landing is assured prudence suggests that the engine should be switched off. There is no great fear that the hot exhaust manifold will ignite any liquid petrol or petrol vapour; and if the engine can be stopped from revolving at the moment of a crash the magneto will cease to generate sparks. In other words, there is no point in keeping the engine running after a safe landing is assured; and even less point in doing so when a crash is inevitable with or without the engine. In any case the pilot should get clear of the machine as rapidly as possible after a landing which damages his machine however slightly.

In high altitude flying the management of the engine is simple. Any correcting device for altitude which may be fitted to the carburettor should be freely employed, the golden rule being to give as much correction as is possible without causing a drop in engine speed. The radiator blinds or shutters should be employed as the water thermometer may suggest.

Occasionally a pilot will stop his engine unintentionally, by an accidental movement of a switch or petrol tap, or by a blunder in operating the rather complicated petrol distribution taps fitted to some modern machines, or by throttling it down too far when it is not running well. This mishap is commonly known as "losing the prop." It is possible to restart the engine by diving at a speed which rotates the pro-

peller fast enough to restart the engine; whether this expedient is practicable will depend upon the altitude. The length of the necessary dive will vary with several factors, including the willingness of the engine to respond, but a minimum of 500 feet may be estimated. It is clear that 500 feet cannot lightly be sacrificed when flying at low heights over country which does not abound in good landing grounds; but loss of height is unimportant when the machine is flying at altitude.

Perhaps an engine requires most humouring in long descents. Carburation and lubrication alike require consideration. A good deal of petrol may pour into the carburettor during a steep descent, and a good deal of oil will enter the combustion chambers and foul the plugs. Further, if the temperature is low the entire engine will become chilled and the radiator may freeze. An expert pilot who is descending to land and has already selected a trustworthy landing ground will not worry about such possibilities. But these phenomena must be borne in mind by a pilot who likes to keep his engine in reserve for correcting an ill-judged landing, or who is merely coming down after a storm or through clouds to pick up his bearings. In either case a little patience is an infallible remedy. The pilot must sacrifice the pleasure of descending on a single lengthy slant or interminable spiral, and at every 2000 feet level or thereabouts flatten out and do a short circuit on three-quarters throttle to warm the engine up, scour out the carburettor and cleanse his sparking plugs.

This chapter may well conclude with a warning to treat new engines very gingerly. They should never be used for flight until they have been given repeated runs at small throttle openings on the ground. It is not wise to run them at all without employing special lubrication safeguards, such as oiling by hand all parts which are accessible, opening up the cambox and inserting half a pint or so, charging the tank with heated oil which is sure to circulate freely, filling the radiator with hot water to procure early and equal expansion of the cylinder blocks, and so on.

CHAPTER X

INSTRUMENTS AND ACCESSORIES

So recently as 1916 there was a marked tendency amongst pilots to despise the instrument board, and this baneful notion dies hard. It is yielding to the improved quality of modern instruments, and to the realisation that flying in fog, clouds or darkness is only possible with the aid of instruments, and will be a normal practice when commercial flight develops. The pioneers used to say that a good pilot could fly round the earth with a compass and an air-speed indicator; but the modern scientific pilot has come to appreciate all the gadgets with which his dashboard bristles. They may be subdivided into engine instruments and aeroplane instruments.

ENGINE INSTRUMENTS

1. *The Switch.*—Two separate ignitions are fitted for safety. They may be controlled with a switch possessing a single knob or handle, capable of being put in four positions, viz. both ignitions on, either ignition on separately, both ignitions off. Or two separate switches may be fitted, each with "on" and "off" positions. Battery ignitions usually have removable key switch handles, to prevent meddlesome people from exhausting the battery. Magneto and accumulator switches work on different principles. Both positions of a magneto switch leave a path open to the current, but in the "off" position the current is short-circuited, so that it cannot travel via the plugs. An accumulator ignition switch breaks the circuit, so that no current can flow.

2. *The Revcounter, or Tachometer.*—The dial of this instrument is graduated in fifties and hundreds of revolutions per minute. It serves several purposes. Before each flight it shows whether the engine can reach a standard speed, and so acts as a test of "tune." With high-compression engines, a

limit of speed is set at low altitudes, which the pilot will not exceed if he watches his tachometer. With all engines there is a limit of speed beyond which it is unsafe to run continuously, as the internal stresses mount up enormously towards the higher speeds. Finally, it is only permissible to run an engine at the highest safe speed for very short bursts. So the r.p.m. (revolution per minute) stipulations of an engine designer may read as follows:

Maximum r.p.m. in ground tests	1300
Maximum r.p.m. below 6000 feet	1400
Maximum r.p.m. for prolonged work at altitude .	1500
Maximum r.p.m. for five-minute bursts at altitude	1600

3. *Petrol Gauge.*—This informs the pilot approximately how much fuel his tanks contain. It is seldom precisely accurate.

4. *Petrol Pressure Gauge.*—This registers the air pressure in such petrol tanks as are pressure fed. The pressure at which it operates is governed by an adjustable relief valve, which should always be set to operate at a maximum of 3 lbs per square inch.

5. *Pressure Pump.*—This is a pump for providing initial pressure in the fuel tank by hand, before the service-pump, operated by the engine or by a windmill, comes into action.

6. *Oil Gauge.*—This registers whether the oil is circulating or not, and in most cases further records the pressure of the circulation. In the latter case the directions on p. 95 should be studied in connection with the engine-maker's instructions. Rotary engines are generally fitted with a pulsometer. This is a small glass dome in which a cushion of air is compressed by a column of oil. At each stroke of the pump the air is compressed, and the oil can be seen to "pulsate." The pulsations show that the pump is working properly, and the rate of the pulsations serves as a revcounter, since the pump is geared to the engine in a known ratio.

7. *Radiator Thermometer.*—This is a distant-transmitting thermometer, plunged in the cooling water. When the proper reading is known, the instrument informs the pilot before each start if his engine is sufficiently warm for a revolution test, and it also acts as a warning if the engine overheats during flight.

8. *Oil Thermometer.*—Very occasionally a second thermom-

eter is installed to inform the pilot when his oil is sufficiently heated during ground tests, and when it is becoming too hot in a flight: in the latter event he can dive with his engine throttled down, and cool the oil.

9. *Radiator Shutter.*—Now that high-altitude and winter flights are possible, a radiator large enough for low altitudes will over-cool an engine at great heights or in winter, and adjustable blinds or shutters are often provided. They should be adjusted in flight after study of the radiator thermometer, but must always be set open when the engine is being warmed up on the ground. Otherwise the water may boil before the oil is fluid.

AEROPLANE INSTRUMENTS

1. *Compass.*—The "card" on which the various "points" (N., S., E., W., and their various subdivisions) are marked, is suspended so that it swings with the magnetic needle, and an indicating mark leads the pilot's eye to the "point" towards which the aeroplane is flying at any moment.

Compasses require careful setting in three main respects. First of all, they must be mounted dead level on the dash when the machine is in its flying position. Secondly, they must be corrected to compensate for any masses of metal in the machine which may attract the needle away from the magnetic north. Such an error is called "deviation," and the amount of deviation may vary as the weight and disposition of such loads as tools and guns are altered from time to time. Deviation is corrected by fitting tiny magnets in suitable receptacles. Thirdly, it must not be forgotten that the "geographical" and "magnetic" north do not coincide: the pilot steers by maps based on the geographic north and with a compass which points to the magnetic north. This error is called "variation," and varies in different localities at different times. In 1918, in the British Isles, the average variation is about 15° W., 1/24 of the circle, which means that a compass needle pointing to "N." is pointing fifteen degrees west of the geographical north.

Two details affecting the use of the compass should be grasped by the novice. The first time he flies in a cloud, he will see his compass card spinning, and imagine that his compass has "gone mad." What is really happening is that the aeroplane is following an erratic course, as the pilot can

see nothing to steer by; and the compass is faithfully trying to point north through all the mad gyrations of the machine. The machine should be kept on a steady course, as far as "bumps" permit, by centralising the joystick and the rudder, and either gliding or keeping the engine on a fixed throttle opening. The compass will then register a readable course.

Secondly, when flying in a side wind, the aeroplane will "drift" away from the wind. For example, if a machine is pointed due north with a strong wind blowing from the east, the aeroplane will be blown or "drift" westwards, and its actual course across the ground will not be a straight line across the map to the north, but a line somewhere between north and west. To keep a map course due north under such conditions, the aeroplane is pointed into the wind just enough to balance the drift. The compass course for flying due north under such conditions will therefore be north with a certain amount of east, say N.N.E. The compass course is worked out roughly before starting, with allowance for the strength of wind blowing across the ground at the time; and any error in the reckonings is balanced by reference to the map, the compass, and the ground landmarks during the actual flight.

2. *Airspeed Indicator.*—Next to the compass, this is the most valuable of the instruments, as the machine cannot stall so long as it is kept moving faster than its "minimum flying speed," and the meter gives the pilot earlier warning of the danger point than a "flabby" sensation through the controls can do. The commonest pattern is the Pitot head. This consists of two tubes, the ends of which are mounted in front of the machine, but out of the way of the slipstream from the propeller. The end of one tube is open, and admits the full air pressure, i.e. a total combined from atmospheric pressure, wind, and speed. The other tube end is protected from wind and speed pressures, but registers atmospheric pressure. The other ends of both tubes are connected to the body of the instrument in the cockpit, one on each side of a flexible partition, which moves as the difference between the pressures in the two tubes varies. The movements of this partition are connected by suitable mechanism to the needle on a dial, so as to register in miles per hour. This meter affords no direct indication of the ground speed.

3. *Altimeter.*—The commonest type is operated on the aneroid principle by the reduction in the pressure of the

atmosphere as height above the earth's surface is increased. Such instruments are only partially satisfactory. They are always late in registering, and so form an unsafe guide when descending in the dark: when they register 500 feet the machine is actually much lower. Again, their readings are affected by barometric pressure, which of course changes from day to day and sometimes from hour to hour. Thirdly, the dial is set to zero at the start of each flight, and the level of this setting will act as the zero throughout the flight. So if the zero is set on an aerodrome 100 feet above sea-level, the altimeter will read "0" even when the machine is 100 feet up over the sea; or will register "0" if the pilot approaches Ben Nevis at 100 feet up in the dark.

4. *Sideslip Meter.*—As explained on p. 92, a piece of ribbon tied to the intersection of two wires in the forepart of the machine is the best recorder of sideslips. When the machine is travelling straight ahead or an accurately banked turn, the ribbon will trail out along the centre fore-and-aft line of the machine. If the machine sideslips on a turn, the ribbon will trail outwards in the direction opposite to the slip.

5. *Inclinometer.*—This is a cross-level, often of the spirit type, designed to show the pilot whether the aeroplane is on a level keel, or at what angle it is banked. The fault of most inclinometers is that they are affected by centrifugal force, and so fail to give a true reading on a turn.

6. *Gradometer.*—This is a fore-and-aft level, intended to show whether the nose and tail are level, and if not, the angle at which the machine is climbing or descending. The commoner types are affected by sudden changes of speed, exactly as the pilot is made conscious of varying pressures on his body during acceleration or slowing down.

A good many pilots prefer a crude but effective home-made instrument to both the above. A wire or string is fastened horizontally taut between the two front centre section struts, and in line with (*a*) the pilot's eyes, and (*b*) the horizon, when the machine is flying level. If this "horizon string" is tilted across the horizon line, the machine is flying with one wing down. If the string is above the skyline, the machine is climbing; if below, the machine is descending. The horizon string is useless in clouds and at night, but is not affected by centrifugal force or by changes of flying speed.

7. *The Watch.*—It may seem absurd to rank a watch as an "aeroplane instrument," but in all serious flying it is invaluable, and should therefore be of excellent quality. In conjunction with the map and compass it is useful in determining position ; for example, a pilot has been flying for an hour on a calm day at 1450 r.p.m. by the revcounter. He cannot recognise any known landmark in the district beneath him, and is therefore " lost " ; but his machine must have done say 80 miles in the hour under the conditions named, and the map shows that there is a big forest 100 miles from his starting-point. Twenty miles is equal to 15 minutes. He decides to hold on his course for another quarter of an hour and to watch for the forest. In eleven minutes he sights the forest, refers to the map, and picks up an accurate course to his destination. Or again, the watch tells him when his tanks are nearly empty, for the " tankage " of a machine is reckoned by the number of hours' flight it provides. Finally, the watch warns him when night is approaching, and so saves him from being forced down between aerodromes by dusk.

It may perhaps be added that when the War is over, any published work on aeroplane instruments will need to be re-written. It is impossible to imagine that the pilots of the Independent Force, R.A.F., reach distant objectives through mist and darkness without better instruments than are described above. Similarly, our ground-strafing pilots can hardly fly far behind the enemy lines on moonless nights and at low altitudes without assistance which it is impossible to describe. The post-war pilot will make far more use of his instrument board than his pre-war predecessors.

CHAPTER XI

FLYING ACROSS COUNTRY

So far as a prolonged flight is concerned, a comfortable and successful journey depends upon preparation. The idea of sitting back in the cockpit, and either following a railway line or spotting landmarks with the aid of a map is illusive. A map may be blown overboard, or jam in its carrier. A sulky engine or a series of violent bumps or a few wreaths of cloud may cause a great deal of trouble. Tolerably accurate navigation is easy for a skilled man without the help of a map, and is possible when the ground is invisible, or when the course lies across wide waters in which no landmarks exist. In any case, proper navigation methods should be used, as a standby if vision should fail. The route is traced on a map, and the necessary allowances are made for the compass error. The compass course is thus determined ; the distance of the trip and the speed of the machine in still air at normal engine revolutions are known. So the pilot knows that if he flies say N.N.E. for an hour and a half at 1500 r.p.m., he will be approximately over his desired destination, subject to wind allowances.

Wind allowance is easily made, as follows (fuller details may be sought in any book on navigation) :—

(1) Draw a straight line on the map from the starting-point (S) to the destination (D).

(2) From S draw a line SW in the direction from which the wind is blowing : and end this line SW at a point W as many miles from S on the map as are represented by the speed of the wind ; e.g. if the wind is blowing at 20 m.p.h. from the west, W will be 20 miles east of S on the diagram.

(3) Take a pair of compasses, and set them by the scale on the map to the number of miles in the speed at which

it is proposed to fly: e.g. if the machine is to be flown at 60 m.p.h., set the compasses to the distance given for 60 miles on the map scale.

(4) Set the sharp point of the compasses at W, and draw an arc to cut the line SD at X.

(5) Now set the compasses to the distance between S and X, and read this distance off in miles from the map scale.

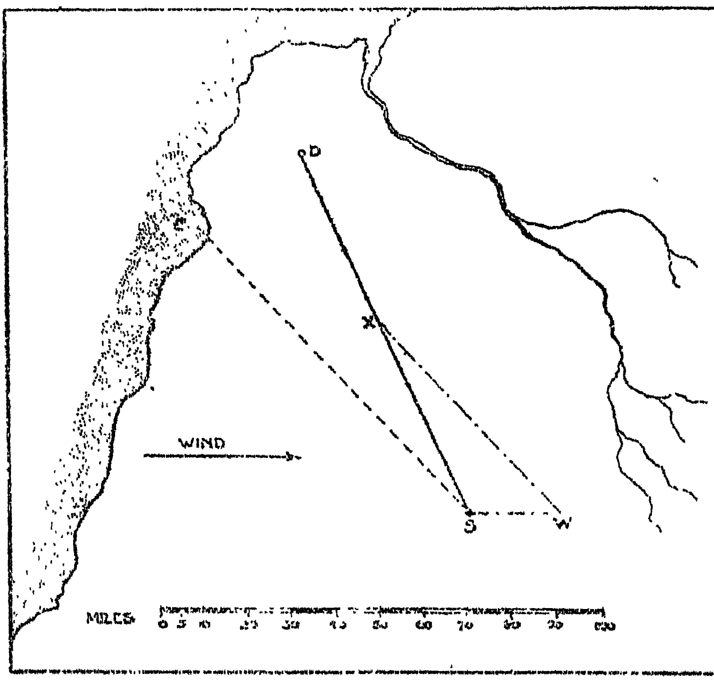


FIG. 40. Plotting the compass course for a cross-country flight. The wind is blowing from the west at 20 miles per hour.

SX then gives theactual distance which the machine will cover along the line SD in one hour, supposing that the wind speed and direction has been accurately judged.

The compass course is also given, being the line WX, or rather a line starting from S and parallel to WX, e.g. SC, as shown in dots in the diagram. Throughout the flight, the

machine will point in the direction SC, though flying slightly crab-wise up the straight line SD. To be quite accurate, fifteen degrees west should be added to this line, as explained on p. 105. But for short-distance daylight work when landmarks can be picked up by eye, such refinements are unnecessary. Needless to say, long-distance night flying or oversea flights should only be attempted by pilots who have been thoroughly trained in the principles of navigation.

A careful pilot will "learn his map," and will start his flight with a list of mental notes, e.g.—"at 3.15 I shall pick up the reservoir at X—— ; at 3.45 I shall pass slightly to the west of the big railway junction at Y——," and so on. Alternatively, the points due to be passed at certain times may be marked in black ink on a roller map, and if sense of position is lost, the pilot need only glance at his watch, and descend low enough to identify some prominent object indicated on the map in the neighbourhood which he must be crossing.

GAINING HEIGHT

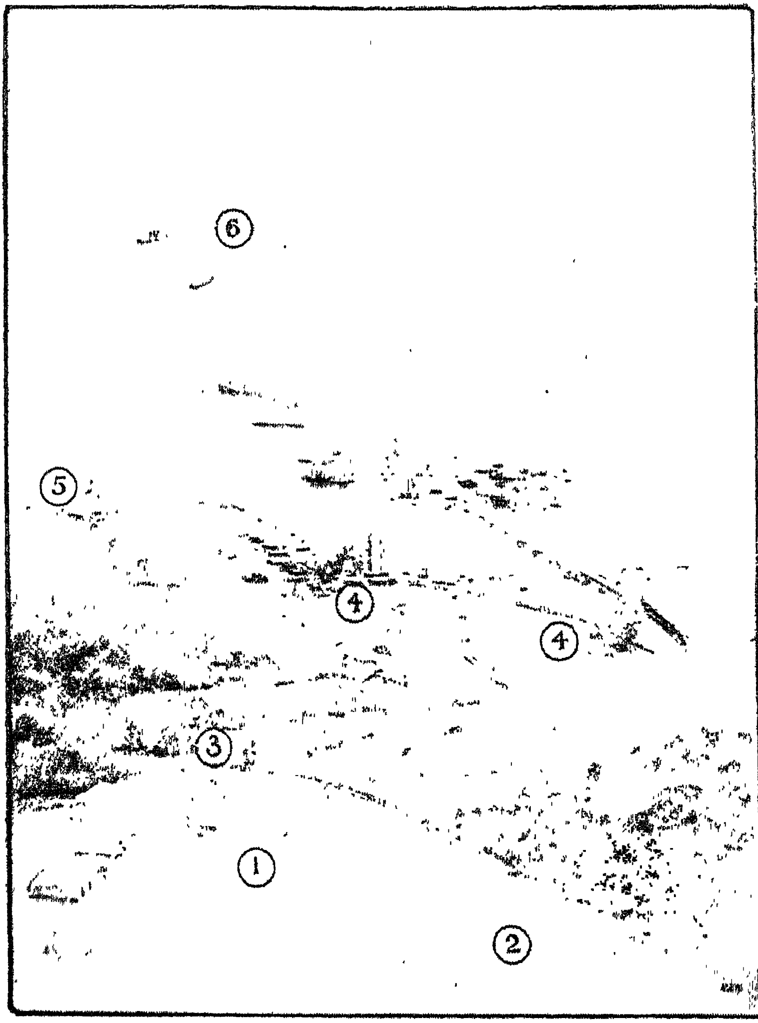
Cross-country flying is not attempted at a less altitude than 3000 feet, which is above the bumpier air strata, gives a wide range of vision without rendering steering landmarks unduly small, and gives a wide area of selection for a forced landing in case of an engine breakdown. There are two good reasons for gaining this height in a series of spirals above the aerodrome. In the first place, this method ensures the actual journey starting from a fixed point on the map, and renders the speed and distance system of taking bearings more reliable than if the trip commences with a long slanting climb on the compass course. In the second place, the calculated allowances for drift can be checked when 3000 feet is gained. Some big landmark on the map course will now be visible. The pilot flies towards it, and reads his compass. The wind at 3000 feet may differ both in force and direction from the wind at ground level. Any variation in force can be judged on arrival at the first "time note" on the map. In the aerodrome map room the pilot judged that he should reach Bloomville, 15 miles away, at 3.15 p.m. He arrives there at 3.12 p.m. Obviously, the wind is not stopping him as much as he expected, and instead of passing Mudtown at 3.30, as calculated, he may expect to be there at perhaps 3.24 p.m. The direction

of the wind should, however, be directly verifiable at 3000 feet. In the map-room he plotted his compass course as N.N.E. But as he heads from the aerodrome for the cathedral at Wyeminster, he notices that his actual compass course is nearly N. by E., i.e. nearly ten degrees more west than he has calculated. He holds this course till he picks up Bloomville, 15 miles away, and then picks up another landmark, and notes if the wind is veering at all. These simple illustrations indicate that route-finding is tolerably simple with the combined use of the map, the compass, and wind allowances. It is not implied that such elaborate preparations are made for short-distance flights out of sight of the aerodrome. For these a preliminary study of the map will acquaint the pilot with the whereabouts of a few salient landmarks—reservoirs, large towns, forests, railway lines, etc.—and he will steer by these. Special instruments are essential for crossing large sheets of water, a type of distance flying which is still in its infancy. In crossing narrow straits, such as the English Channel, the pilot starts by climbing to a great height, and flies by a compass course. For example, in flying across the Straits of Dover for the first time the pilot will work out a compass course from his starting-point on the English side to the selected destination on the French coast. He will correct this to suit the prevailing wind. He may then climb to say 10,000 for two reasons: in the first place, should an engine failure overtake him in mid-Channel at this altitude, his gliding angle will land him either in England or France, at his discretion; in the second place, he will be able to see both coasts throughout the whole of his journey if the visibility is good, and can check his compass course by reference to the map and the coast-lines. Long distance flying by night or over water should only be attempted by expert pilots who thoroughly understand navigation.

TROUBLES EN ROUTE

Three kinds of trouble may assail the cross-country pilot, and sooner or later all of them will befall the man who flies regularly. The commonest is a change of weather, the most tiresome is engine trouble, and the most humiliating is getting lost.

Changes of weather appear to occur with astonishing suddenness, the usual reason being that "weather" comes up



How to Judge Direction of Wind during a Flight.

1. Wind cone on aerodrome
2. Cloud shadow moving across ground.
3. Windmill
4. Smoke from factory chimneys and trains.
5. Flags on staff.
6. Smoke from steamers.

To face page [illegible]

from behind the pilot, whose attention is concentrated on his machine and on his route-finding, and rain, hail, mist, or snow catch him unawares. As certain kinds of weather are genuinely dangerous to the most skilful man, the careful pilot will keep as watchful a lookout as if he were flying over enemy territory. Fog is always dangerous, because it usually hangs so low that the selection of a good emergency landing ground is reduced to a lottery. Snow is equivalent from every standpoint to the densest fog. A thunderstorm is usually accompanied by the most gigantic bumps: the air currents may move vertically upwards or downwards with the force of a gale. Consequently it is sheer folly not to descend when fog, snow or thunderstorms threaten. Rain and hail may be braved with impunity, though prolonged flight in either will damage a propeller. The approach of night is, fortunately, always perceptible in European latitudes; its only significance is to determine whether the light permits one to reach an intended destination, or suggests a premature descent at a convenient landing ground.

ENGINE TROUBLE

The featherweight "hotstuff" engines developed for war purposes have proved creditably reliable, and when peace flying develops a little weight will be sacrificed to the cause of reliability, so that engine failures in the air will generally be ascribable to the carelessness of mechanics. At the same time no engine ever records a clean sheet throughout its period of service, and the basic qualification for cross-country flying is the ability to make a safe landing at short notice on the best available piece of ground. Chapter VII therefore suggests the sort of practice which the long distance pilot must indulge in. In this connection it may be stated that it is far safer to charge a wall or hedge at twenty miles an hour than to stall the aeroplane at a height of twenty feet. Quite a small aeroplane weighs a ton with full load, and gravity is a serious factor where such weights are concerned. In charging a hedge at moderate speed, there is a sudden and unpleasant stoppage, which shakes the pilot; the stoppage is possibly followed by a cartwheel, and the machine sustains minor injuries. But when a ton is dropped twenty feet or so, the structure collapses, and the chances of personal injury are considerable.

The whole secret of a forced landing lies in the selection of the ground. A pilot flying at 3000 feet over practically every part of the British Isles can rest assured that there is a safe and easy landing somewhere within his gliding range, and that he is in no danger provided he uses his eyes, his common sense, and his previous experience. Eyesight stands first, because uneven and sloping fields look flat from the air, and deep hay closely resembles short turf, whilst tall trees may pass for a low hedge, and telegraph posts may pass unseene As soon as the engine plainly indicates that an immediat. descent is inevitable, the landscape beneath must be sharply scanned, the available fields keenly scrutinised, and any facts which mere vision can collect be quickly weighed. At the same time the direction of the wind is picked up from watching the smoke-trails above chimneys, washing hung out to dry, the waving of trees, and the angle from which the selected field must be entered is noted.

As the descent towards the selected field commences, common sense takes up its work. Telegraph wires may be expected at the edge of fields bordering roads. Ground often slopes down steeply towards brooks.

Previous experience is invaluable, because it tells a pilot's instincts whether his glide will reach the selected field or not. The air holds few sensations worse than that of being several thousand feet up with a "dud" engine over country which offers few possible landings, and being in grave doubt as to where the natural glide will bring the machine to earth. For this reason the would-be cross-country expert should practise imaginary forced landings, which can easily be done in the neighbourhood of the aerodrome. Day by day he throttles down his engine at varying heights and at varying distances from the aerodrome. Then he picks a likely looking field, and glides down towards it. By dint of such practice he comes to know by eye whether he can or cannot reach a certain spot without the help of his engine. Nothing but practice can confer this knowledge. It is obviously the last portion of the glide which makes or mars the approach. In forced landings without the engine the pilot has a certain control over distance. He cannot extend the distance which his glide will carry: if his minimum air speed is 50 m.p.h., and that speed is attained in gliding at an angle of 1 in 7, he must land within a circle on the ground traced by drawing lines to the ground at 1 in 7

from the point where his engine failed. But he can land anywhere in that circle, e.g. vertically under the point where the engine failed, or half-way between that point and the circumference of the circle. For he can spiral down, turning into the wind (by preference). On the other hand, he cannot help himself by steepening the angle of a straight glide. Suppose he feels that his natural glide will overshoot the selected field. He puts the nose down, and glides at a steeper angle. His speed increases, and though he may get into the field, he will either make a fast, bouncing landing with a lot of run on the machine, or in flattening out near the ground he will foul the hedge at the far end of the field. The ideal is to select a field which is within comfortable reach of the glide, and to spiral with judgment in the upper portion of the descent, so that the concluding stage of the glide is simple.

During the lower portion of the descent the selected field seldom looks quite so inviting as it appeared from 3000 feet. The lie of the ground becomes more plainly visible, and the pilot is lucky if his judgment of distance is not accompanied by a certain anxiety about gulleys or ditches or ridges or a rough surface or a patch of very soft ground. For this reason it is best to aim at a farm, rather than at a single field; and if one field proves disappointing on closer acquaintance, one of its neighbours may turn out to be unexpectedly suitable. During the descent the pilot is spiralling or making a series of figure of 8 turns, and enjoying repeated views of his objective at distances which are continually shortening. Finally he skims the fence or hedge remote from the windward end, and lands with as much run as it is safe to give. In deciding at what height to flatten out, he remembers that ploughed land or boggy land or standing crops or roots act as chocks on the landing wheels, and induce cartwheel somersaults. On a bad surface a "pancake" landing is the safest course. The worst forced landing imaginable is a very small field with a high obstacle (e.g. telegraph wires) on its leeward side, and one of the holding surfaces described above. The ideal landing is similar to an aerodrome—a large area of hard, smooth surface with no obstacles at the leeward end.

GETTING LOST

Getting lost in the air is commoner than a novice would imagine, and is variously ascribable to carelessness in prepar-

ation, slovenly navigation, reckless flying over water, and clouds or fog. Expert pilots strike a novice as absolutely pusillanimous in their reluctance to ascend to any height. The sky may be apparently clear, and the tyro is angry because he is not allowed to go up himself. The trained eye has noted that there is a faint smother of cloud wreaths away to windward, and in ten minutes there is no visibility above 1000 feet. A pilot caught by such weather at 3000 feet, five miles away, would have to come down where he could. Under such conditions a reckless pilot with a month's experience is quite likely to attempt a flight to an aerodrome fifty miles away without even taking a map. The instructor flew there with him last week, and it is only necessary to follow the railway. All sense of direction is easily and quickly lost in snow and fog or over water: in flying near the sea, special precautions are doubly necessary. The inexperienced navigator should always descend in preference to risking the loss of his bearings. If he is lost in good weather, he should come down in the attempt to discover his whereabouts. He may be able to read the name-board on a railway station, or to inspect a railway junction or village so closely that if he ascends to 1000 feet again and studies his map closely, he may solve the puzzle. Alternatively, he may make a forced landing and enquire.

RISING OUT OF A FIELD

Getting up out of a field is not to be attempted without thought, especially if the engine has cooled down, and prudence suggests that it should be warmed up before taking off, whilst no chocks or trustworthy assistants are available. The novice would be well advised not to attempt the task. Many machines have been smashed up through clumsy attempts to complete a flight after such an interruption. The pilot really needs assistance in starting up the engine, assistance in steadying the aeroplane whilst the running of the engine is tested, and not improbably assistance in taxying the machine to its starting-point if the ground is holding. Moreover, the inexperienced pilot will quite possibly forget that a soft field is not a hard aerodrome, and will try to take off too soon in his natural anxiety to clear the hedge at the far end. The whole procedure is so dangerous for an incompetent man that printed advice is deliberately withheld.

A few journeys with the breakdown gang and other rescue parties are preferable to a library of books in this emergency.

When a pilot has made several successful ascents from awkward fields, he should still bear in mind that a machine rises most quickly when it is lightly loaded, and that any appreciable obstacles, such as farm buildings, between the aeroplane and the wind create pockets of dead air, in which the wings can obtain very little lift.

CHAPTER XII

STUNT FLYING

"STUNTING" is military slang for performing those aerial acrobatics which owe their birth to the showman and their evolution to the machine gun. Pégoud, the French airman, looped the first loops partly out of devilry, partly to make a name for himself, partly to advance the technique of flight, and most of all to attract the public to flying exhibitions. Shortly afterwards the European War broke out, and stunt flying suddenly blossomed into a necessity. In one sense, it is merely a species of manœuvre, which enables an airman to surprise his assailant in attack or defence; more accurately, it is to the fighting pilot what "cover" is to the land forces; in other words, it is a protection against gun-fire, for the best marksman experiences difficulty in hitting a target which behaves like an inebriated eel.

THE SAFETY OF STUNTING

In considering how far the average pilot will "stunt" after the war, the factor of safety has to be considered. Given a capable pilot, stunting is neither more nor less dangerous than the most sedate forms of flight. The necessary conditions are that stunting shall be reserved for tolerable altitudes, and shall only be practised on sturdily built machines. So far as altitude is concerned, practically any aeroplane will automatically recover itself from any position when the controls are centralised, provided that there is room underneath the machine for a long drop before ground is reached. Even an unstable fighting scout, deliberately designed to twist and whirl like a winged leopard, will recover automatically from the craziest postures whilst dropping say 600 feet: the main

exception is that some of these acrobats are rather loth to come out of a spinning nose dive without assistance from the pilot. On the other point, the structure of every aeroplane can be stressed to the point of collapse. Most war planes are built to withstand six times the maximum stress to which they are subjected in ordinary fighting. But if a scout is dived steeply from 20,000 feet and flattened out very abruptly at 2000 feet, some of the parts bear stresses running into hundreds of tons: wood and wire and linen cannot resist forces of such magnitude. Nevertheless, so long as stunting is reserved for altitudes exceeding 1000 feet (5000 feet is, of course, a safer margin), and common sense is exercised in coming out of long, freakish descents, stunting is perfectly safe.

STUNTING AFTER THE WAR

In all other sports adventurous youths deliberately take every imaginable risk, and the same will occur in flying. The need for stunts will disappear with the advent of peace, but no young pilot will consider his education complete until he can perform every stunt which has ever been invented. Until the law interferes, a minority of pilots will probably earn handsome money by demonstrating the more spectacular tricks close to the ground. In any case the military designers and pilots will continue to study stunting from a professional standpoint, although the catalogue of stunts is already nearing completion, and future inventors can do little beyond perfecting or accelerating tricks which are already ancient.

LOOPING THE LOOP

As the loop was the father of all stunts, it deserves pride of place in our catalogue; and in this connection it is interesting to note that many living pilots have looped the loop on their first flight, though such men were certainly undergoing an intensive form of training.

The machine is first climbed up to a considerable height; as this stunt commences with a long dive, 3000 feet is none too high for the commencement. Begin by getting up a considerable speed in a long dive. The requisite speed will

vary with the machine, but the average is perhaps eighty miles an hour. Such a speed can be worked up in two ways, viz. by a short, steep dive, or a long dive at a gentler slant. The gentler the angle of the dive, the less will be the strain of pulling the machine up at the start of the loop. Consequently a good loop begins with a dive which is steeper than the natural "engine off" glide, the joystick being pushed forward part of its travel, and not left central. At the same time a dive before looping should not approach a nose dive in steep-

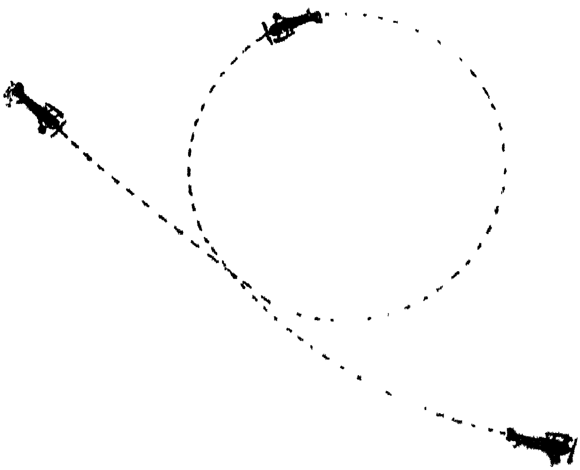


FIG. 41. A perfect loop.

ness. This dive is also faster than an "engine off" glide, because its angle is steeper and the engine is on. But it is not a "nose dive," and the machine is very far removed from being vertical. As soon as the speed advised by the instructor—say, 80 m.p.h.—is attained, the stick is firmly but gradually brought back. If the pilot tries to jerk it back suddenly, the machine will be subjected to huge strains, and the results will vary according to its design. Under correct handling of the control the gradual pull will get the stick right back soon after the bottom of the loop has been passed, but before the machine is climbing really steeply. The engine is kept on

until just after the pilot is over the top of the loop and he begins to see the ground again. Half-way down the back of the loop, i.e. at the position represented by three or nine o'clock on the face of a watch, according to the direction of the loop, he gradually pushes the stick back to the centre position.

If the loop has been well done, the pilot will have no sensation of being suspended by his safety belt, for the swirl of the loop will keep him in his seat all the way round. Any sensa-

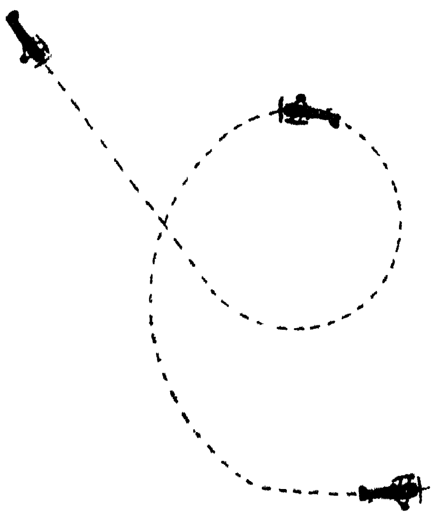


FIG. 42. A bad loop.

The dive is too steep. The stress on commencing the loop is too heavy, and the aeroplane is also pulled out too suddenly. The pilot will not be held in his seat by centrifugal force.

tion of weight on the strapping is a proof that the loop was untrue.

The beginner should loop upwind for preference, and the use of a stationary engine (not a rotary) is advised. The aeroplane should be trustworthy, which implies the selection of a good make, a sample which is not too old, and a special vetting by the best rigger available. No loose objects should be allowed in the cockpit.

THE NOSE DIVE

A nose dive is simply a very steep dive, and may be performed with the engine on or off. In early essays the engine should emphatically be off, and the angle should not be unduly steep. Since any aeroplane dives automatically when its engine is off and its joystick is central, it follows that it will dive faster and more steeply, if the stick is pushed forward a little. The angle can be further stiffened by pushing the stick forward still more, and the speed raised to incredible figures by keeping the engine on. A nose dive with the stick far forward and the engine full on represents treatment to which only the very hardiest machines of special construction should be subjected. It is obvious from the above details that nose-diving demands pluck rather than skill: but skill

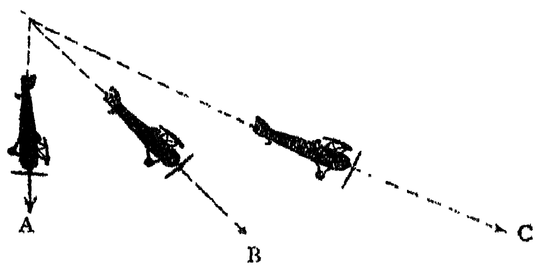


FIG. 43.
A. Vertical nose dive. B. Nose dive. C. Glide at natural angle.

is essential to pulling a machine out of a nose dive, as the wings may collapse if the stick is hauled back too quickly. Most air-speed indicators suffer from "lag," i.e. they respond rather slowly to changes of pace, and register the speed at which the machine was travelling a few moments ago rather than the actual speed at the moment. Consequently, if the pilot wishes to slow right down, as the "bursting" sensation produced by a high-speed dive may suggest, he should not restore the joystick to its middle position until the indicator shows the minimum flying speed or little more. The first nose dive should begin at a good height, should not last long, as the atmospheric pressure is tremendous, and should terminate at a really safe height in case the excited pilot "comes out" badly, and gets himself into difficulties.

THE "ZOOM"

A zoom is a brief climb at an unnaturally steep angle, and can be performed in two distinct ways. Just as a motor-cycle, driven at its fastest speed, can rush a short hill which it could not climb with a slow start, so can an aeroplane utilise impetus to rush short, steep hills in the air or "zoom." The simplest way of accumulating impetus is to dive rather steeply. If a machine's maximum speed in horizontal flight is 80 m.p.h., the machine can be dived at 90 m.p.h., and will then do a short climb at an abnormal angle if its nose is pulled up. Another and quite common method of zooming is to fly horizontally with the engine full on. Most modern machines will begin to climb with the joystick central if the throttle is opened past the half-way mark. If the throttle is fully opened,

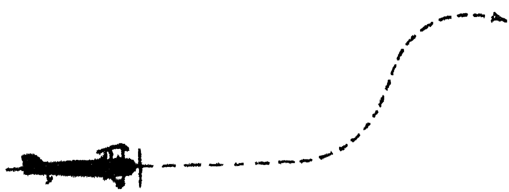


FIG. 44. A "zoom."

and the machine is pinned down to horizontal flight by pushing the joystick forward a little, great speed is attained. Then the stick is sharply pulled back a little, and the machine rushes a hill in the air, so to speak. There are two reasons why this latter form of zoom should be practised high up, before it is risked near ground level. The first is that an inexperienced pilot may be uncertain in holding the nose down, grow nervous, and pull the stick back far enough to cause a leap and a stall. The second is that a zoom always ends in a stall, unless the pilot stops the zoom before stalling-point is reached. The machine can only climb at a fancy angle whilst the impetus lasts. As soon as the impetus dies away, it will be in the position of a brakeless motor-car stopped half-way up a steep hill. The pilot can always tell when the stall is approaching, for the elevators will begin to feel flabby to his hand, when the speed grows too low for them to hold the tail down. When or before this "flabbiness" is apparent, he

must push the stick forward again. If he attempts this stunt near the ground, and is late in pushing the stick forward, a crash will result; wherefore zooming should be learnt at altitude.

FIG. 45. A spinning nose dive, or "spin."
In addition to the vertical speed, the aeroplane acquires a special "spinning momentum," and comes down very fast.

THE SPIN, OR SPINNING NOSE DIVE

It is not possible to generalise about "spins." It is very difficult to get some makes of machine into a spin, whilst others are even more difficult to get out of a spin. Fortunately, school machines are selected from the former variety. Further, certain machines try to get into a left-hand spin when brought out of a right-hand spin: some are more prone to spin in one direction than another: some are best extricated in one way, and some in another. As particular machines grow obsolete very quickly, it will suffice to define a spin, and to describe how an ordinarily stable machine may be made to spin and to come out of a spin. A cork-screw descent in which the spirals are flat and wide is a perfectly normal and safe method of descending: indeed, it is the commonest method of losing height after arriving over a selected landing-place, as it is much easier to judge distance by this method than when a single straight slant is employed. But if this spiral is contracted so that its whorls are of comparatively small diameter, and its downward slant is much steeper, the word "spiral" is dropped, and the term "spin" is substituted. An aeroplane is normally banked over for a turn: the sharper the turn, the more the machine is banked. If it is banked over more than 45 degrees, the rudder and elevators change places to all practical purposes, much as professors dislike the phrase. To take an extreme instance, if the machine is turning so sharply that its wings point

upwards and downwards respectively, the elevators will swing on *vertical* hinges, just as the rudder does when the machine is flying "on its stomach." So they will turn the machine to the right or left, instead of levering its nose up or down as they do in normal flight. Similarly, with the machine in this position, the rudder swings on a *horizontal* hinge, and puts the nose up or down, instead of turning it to right or left. Many of the pioneer pilots were killed in spins because they tried to turn out of the spin by ruddering,

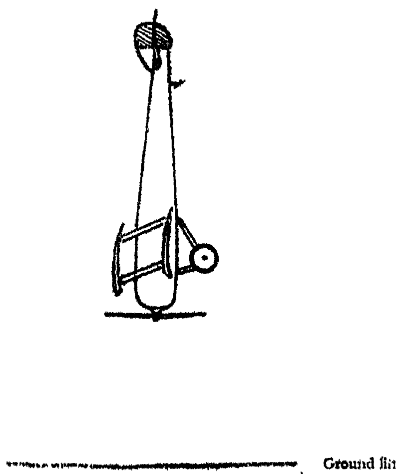


FIG. 46. Diagram illustrating inversion of controls in a spin. Rudder is now working on a horizontal hinge.

whereas at such moments the elevators temporarily exercise most control on turning. Over and above the so-called "inversion" of the controls, a spin imparts a peculiar and very powerful rotary momentum to the aeroplane, which increases the difficulty of recovery.

To get into a spin, bank the machine well over to the right to say 45 degrees, throttle down the engine, and pull the stick back, being careful to get a safe height before the experiment: the higher the better on the first occasion.

The aeroplane is trying to get its nose up and its wings level, by dint of its natural stability. But the elevators are

pulled down, and their hinges are at an angle of 45 degrees. So they tend partly to hold the tail up, and partly to slew the tail across to the right. In other words, they cancel the stabilising efforts of the machine, and the steep corkscrew spin commences. The rudder can hardly be expected to correct matters. Its hinge is by now approaching the horizontal; so if the rudder is pulled down, it will merely quicken up the spin, and if it is pulled up, its small area will not have the requisite effect. Consequently, so long as the joystick is held back, the

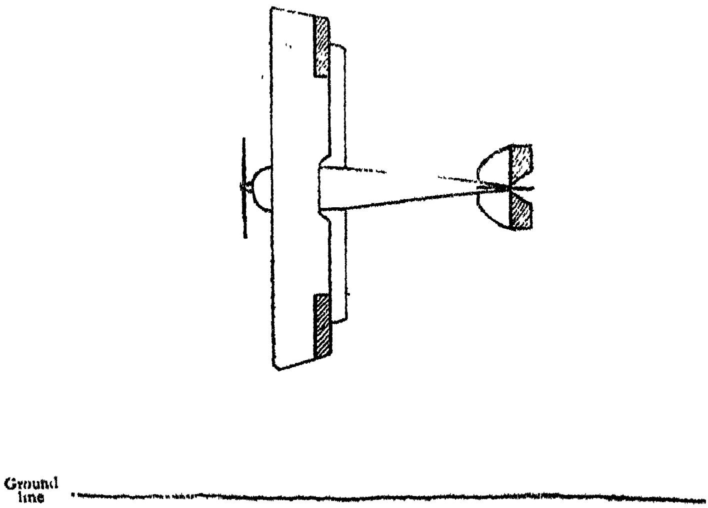


FIG. 47. Diagram illustrating inversion of controls in a spin. Ailerons and elevators are now working on vertical hinges.

spin continues. But as soon as the stick is centralised, the automatic stability of the machine will get to work, and if there is room for the requisite drop of from 200–600 feet the machine will come out of the spin. Unstable machines generally require special treatment to bring them out of a spin, and to prevent a second spin in the reverse direction from developing when spin No. 1 terminates: but they vary so widely that no details can be given here.

THE TAIL SLIDE

The first experience of a long tail slide is one of the most alarming sensations in flight and one of the most agonising for

an ignorant spectator on the ground: but given sufficient height it is quite ridiculously safe. The machine is caused to climb so steeply that it finally stalls, and begins to slide groundwards, tail first, with increasing velocity. When the tail slide begins, the pilot merely throttles down his engine, and centralises his joystick. The machine continues to fall, but as the nose is heavier than the tail, the nose gradually catches up the tail, until the tail slide merges into a flat fall, and at last the nose takes the lead. Soon after the nose takes the lead,

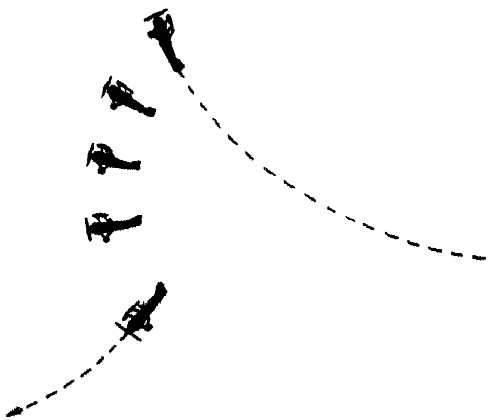


FIG. 48. A tail slide.
The aeroplane, being "nose-heavy" when the engine is not pulling, automatically recovers, and converts the tail slide into a glide as it falls.

the natural gliding speed and angle are attained, and the machine is once more under control. The pilot can either complete the glide and land, or open up his engine and climb once more.

A VERTICAL BANK

Banks seldom reach the vertical, and the term is applied to all really steep banks. As already explained in this chapter, the rudder practically controls the machine in the up-and-down direction when a banking angle of 45 degrees is exceeded. The machine is put on such steep banks by exaggerated use of the ailerons and rudder. The pilot's action when the vertical bank has begun will depend on what he wants to do.

Pushing his upper foot forward will raise the nose ; pushing his lower foot forward will raise the tail. The handling of the joystick is not quite so simple to grasp. The upper aileron is covering a bigger circle than the lower aileron in the same time : it is therefore moving faster, engaging more air, and exerting more leverage. Consequently, the banking effect increases very rapidly. To prevent this, the joystick must be moved in a little towards the centre, if a smooth, even sweep round is desired. Moreover, as the elevator is now in charge of the right-and-left movement, in view of the steep bank, the joystick must be pulled back for a vertical bank.

Coming out of a vertical bank is simple. The machine will regain a level keel if the joystick is pushed over to give the opposite banking : the necessary direction can be imparted by the rudder, which regains its normal function as the wings resume the horizontal ; and the nose can be put down if more speed is required at the end of the manœuvre.

If a machine is put on a vertical bank without enough of the turning effect produced by temporarily using the elevators as a right-and-left rudder, a sideslip may result : and the pilot can get out of this by throttling down and centralising his controls.

THE ROLL

The track followed by an aeroplane in a " roll " resembles one twist of a corkscrew, laid horizontally on its side, and pulled out by two pairs of pliers. Not more than two rolls

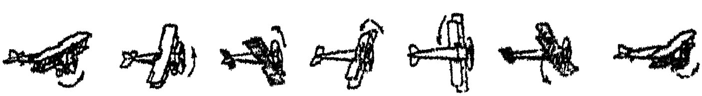
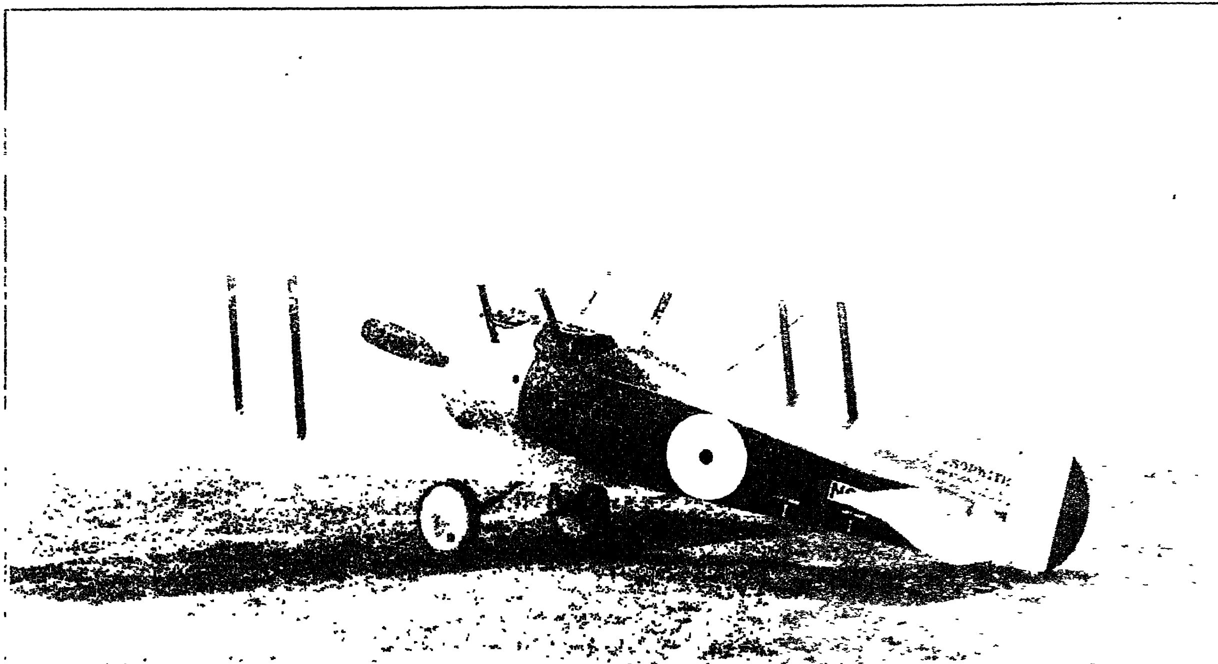


FIG. 49. A roll.

A pretty "stunt" of no particular utility. The machine is at top speed when the roll commences, and stalls from loss of flying speed after from 1½ to 2 rolls if the axis of the roll is horizontal.

can be performed along a horizontal axis : when much height is lost in rolling, the manœuvre begins to have affinities with a spin. Speed is worked up to the maximum by giving full throttle and using the joystick to keep the machine on a



A FAMOUS FIGHTING SCOUT. THE SOPWITH "CAMEL."
(Note the twin machine guns on the nose of the fuselage.)

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horizontal track or nearly so. When full speed is attained, give full rudder and pull the joystick right back. Impetus is lost very rapidly, as the wings are not at any useful angle of incidence during the bulk of the roll. Consequently, at the end of the movement the machine is practically stalling, and this stunt must not be attempted, except at heights which leave sufficient drop for a recovery glide to develop. The roll is sometimes described as a "side-loop": if it is properly done, centrifugal force pins the pilot in his seat, as in the vertical loop, but he should, of course, wear a safety belt.

THE IMMELMANN TURN

This form of turn was first demonstrated by the German "ace," whose name it bears, and secured him many victims in battle because of the speed and unexpectedness with which it changed his direction of flight. Opponents fancied he was

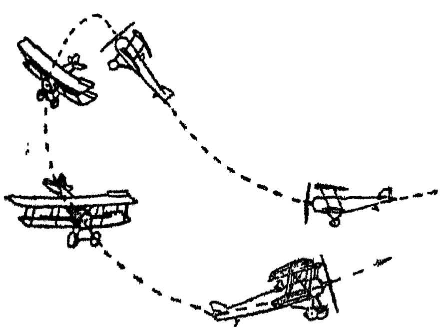


FIG. 50. The Immelmann turn.
The aeroplane climbs as for a loop, and is rolled over sideways when the nose is pointing very steeply upwards.

breaking off a duel to gain a little height, and suddenly he pounced back on them like a thunderbolt. As he executed the turn, it commenced with a zoom: then, as the machine reared up as in the first half of a loop and got on its tail, he would wriggle it clean over sideways till the wheels pointed earthwards again, and dive down once more. The Immelmann turn can also be executed downwards instead of upwards, in which event it is an even better fighting manœuvre

as the speed is kept up. The machine is first rolled over on to its back, so that its wheels point almost skywards, when it is in much the same position as if it were at the top of an ordinary loop. Then it completes the loop, and as it gets to the bottom of the half-circle it is flattened out laterally. To achieve this latter stunt, give full rudder and bank towards whichever side it is desired to roll, pulling the stick right back as well as hard across. When sufficient " roll " has been secured, i.e. about a third of the circle, straighten the rudder, and put the stick on the centre line of the aeroplane, still keeping it right back. As the wings again become parallel with the ground at the foot of the half-loop, the joystick is centralised and level flight is resumed. In fighting, of course, the exact recovery will depend on the enemy's whereabouts, and the rudder and stick motions will vary accordingly. To sum up this rather complex stunt, it consists either of a one-third roll followed by a half-loop, or of a half-loop followed by a one-third roll: in the latter case the turn begins with a climb, whereas in the former the turn involves marked loss of height.

THE FLAT TURN

Turning flatly can be done in two different ways, but is pure ostentation and of no practical value. The simplest way is to cut off the power for an instant, during which the rudder is put hard across, no bank being given. The machine will skid round, and if the engine is swiftly opened up and the rudder straightened out, normal flight will be resumed. Alternatively, the engine may be kept on, in which case the turn will be less abrupt. If the aeroplane is tolerably stable, it will try to bank itself for the turn, and in such cases a flat turn can only be made by putting on just enough of the *wrong* bank to keep the machine flat.

THE FALLING LEAF

The " falling leaf " is a fancy method of descending, which is pretty to watch, but of no conceivable utility, except as an exercise in the use of the controls. It consists of a series of stalls, in each of which the machine is banked over enough to provoke a sideslip. As indicated in Fig. 51, the result is to weave quite a pretty aerial pattern. Each right or left-hand " J " (front v ew) or " hump " (side view) can be varied in

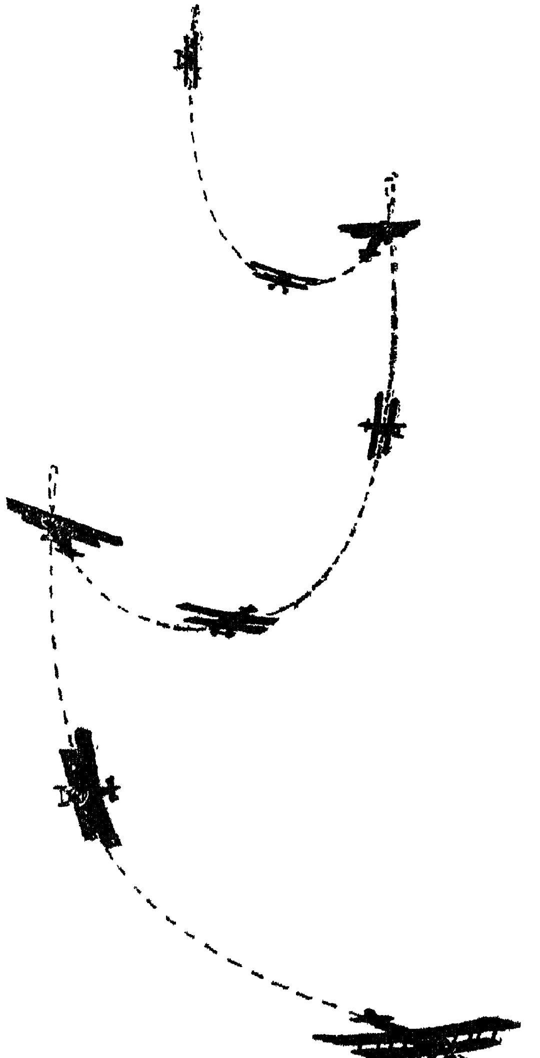


FIG. 51. The falling leaf.

A pretty "stunt" of little practical utility. The machine is here viewed from the front. It is stalled and then side-slipped to the left and right at alternate stalls.

length by using the two alternative methods of stalling ; i.e. the stall can be procured by putting the nose up very steeply with engine on, or putting it up less acutely with little or no engine, using the impetus of diving to climb for the stall. The latter makes a closer and more impressive pattern.

CHAPTER XIII

NIGHT FLYING

NIGHT FLYING looks appallingly dangerous, and feels most alarming at the first essay ; but in actual practice it is as safe as daylight flying with the solitary exception that the success of a forced landing in darkness is a matter of sheer luck. It is true that accidents were not unknown when Zeppelin raids first compelled pilots to experiment in night flying ; but matters have advanced at such a pace that the modern pilot sometimes flies blindfolded in experimental work. The first difficulty encountered in night flying depends on the fact that the average man relies on his instrument board as little as possible, and steers, as he fancies, by instinct and feel. The truth is that he flies very largely by eye, judging his movements by the horizon and visible objects. When he makes his first ascent in the dark, he can see little or nothing outside the machine, and has to revise his methods. Consequently, the first night flight should be made on a thoroughly stable machine, which will take off of its own accord when the throttle is opened, bank itself correctly on all turns, and glide truly when the controls are centralised. This implies that the machine shall be accurately rigged, as well as properly designed. As soon as the pilot is at home in night flying, there is no particular reason why he should not take up a machine which is not thoroughly stable, and fly by his instruments. Instruments are now developed to such a pitch that a good pilot can safely rely upon them to handle an unstable scout machine in darkness : nevertheless, the stable machine is the right machine for the work.

NIGHT LANDING

It goes without saying that no pilot should fly at night if his daylight landings are uncertain quantities. It is true that proper aerodrome arrangements provide brilliant lights for

landing purposes, e.g. the pilot may land down the beam of a powerful searchlight, which carves out a dazzling lane pointing upwind across the aerodrome. But distances are less easily judged amid such lighting contrasts, and the average pilot is more nervous at night than by day. Consequently, a man who misjudges time and distance in daylight landings is not a safe night pilot. Practice makes perfect, and the aspirant may fly and land in twilight before he ventures aloft in moonlight, and make himself at home in bright moonlight, before he flies in inky darkness.

Forced landings at night must always remain something of a lottery, until the whole countryside is dotted with illuminated aerodromes. Until that era dawns, the chief insurance

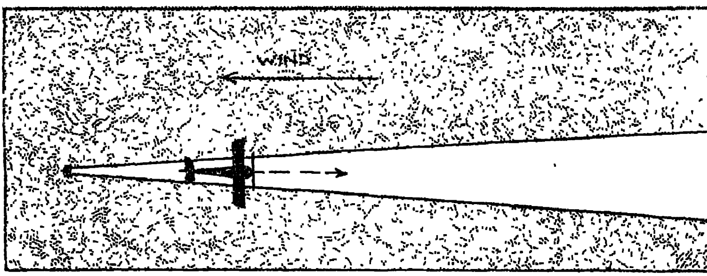


FIG. 52. Night landing with one searchlight. Beam points into wind. The aeroplane lands close over lamp and runs down the beam.

consists in limiting night flying to familiar neighbourhoods, and to nights of such visibility that ground lights give the flier an accurate idea of his whereabouts at heights from which his glide will reach safe landing grounds. These conditions, coupled with a flare or searchlight on the aeroplane—to be used at 100 feet up—afford a fair chance of success. On long night flights elaborate provision should be made with a view to forced landings. Giant machines can carry really powerful searchlights, which should reveal a possible spot for a "pancake" landing unless the descent is made over a very large town. Alternately, a series of flares may be carried. Some of these flares may have "delay actions," so that, for example, one dropped at 1500 feet does not light until it is 500 feet from the ground, when its parachute opens, and falls slowly. The pilot

can recognise the general nature of the country: if it is agricultural, he comes down towards it, and drops at intervals flares which act more quickly, effecting his " pancake " by the light of the final flare. Telegraph wires are practically invisible, and very dangerous under such circumstances. On the other hand, water shows up if there is any radiance in the night, and water offers a safe " pancake."

DODGING OBSTRUCTIONS

Needless to say, the pilot must know the lie of the surrounding ground before he flies by night. Obstacles which seem

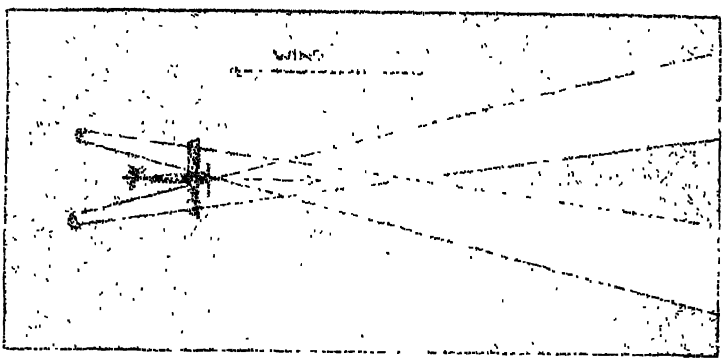


FIG. 53. Landing with two searchlights.
[The beams point up wind, and the machine lands where the beams intersect.

childish by daylight are highly dangerous at night—tall chimneys, church steeples, low hills in close proximity to the aerodrome—all these are easily fouled by a happy-go-lucky flier. There is no real danger of collision with other machines except in the immediate vicinity of the aerodrome. Navigation lights are invariably mounted, white on the tail, red on the port wing, green on the starboard wing-tip. The ground manager of the aerodrome should hold himself responsible for preventing collisions on the ground and vertically above it. No machine should take off or land except under his control; and a system of Verey or other signal lights will presumably be enforced for this purpose.

GETTING LOST

Perhaps the bulk of forced landings at night are due to the pilot's getting lost rather than to any mishap with his engine. Familiar country is quite extraordinarily unrecognisable from the air until the pilot has enjoyed some experience. At night such difficulties are greatly enhanced at any time. An absent-minded pilot may busy himself with the machine for a few

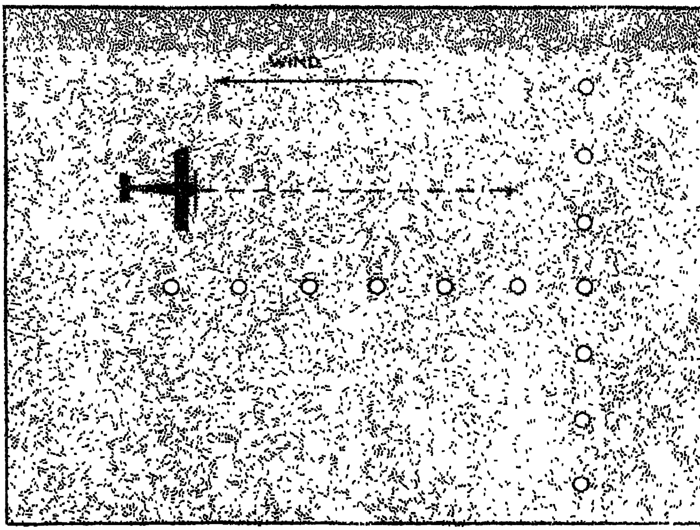


FIG. 54. A night landing "tee" of petrol flares or electric lamps. An "L" is sometimes used.

minutes, oblivious of the fact that he is moving through space at 100 m.p.h.; when the thought of his whereabouts recurs to his mind, he searches the glimmering lights beneath in vain quest for some known landmark. A system of light-houses will probably reduce this danger in years to come; but for the present the night flier must remember that very brief thoughtlessness may result in his being hopelessly lost. Furthermore, mists and fog are far more common at night than by day. Fog almost invariably accompanies the slightest frost during the night; and at any time of year mist may rise from waterways after sunset, and completely

camouflage a familiar countryside. A brook far too narrow and tortuous to permit of a "pancake" may breed a mist which will veil whole acres.

ILLUMINATED LANDING GROUNDS

The lighting systems of aerodromes vary considerably, and some of the most ingenious may not yet be described in print. A common type consists of two powerful searchlights arranged so that their beams converge at an angle. A black "V" thus points to the illuminated patch of turf. This black "V" is always aimed dead into the wind, and its apex represents the point at which the aeroplane should alight. Sometimes a single searchlight is used, in which case its beam points dead up wind, and the pilot skims over the lamp, and lands as close in front of its lens as he can. Sometimes an "L" or "T" of electric lights, petrol flares, or other light signals is preferred. In this case the "L" is laid so that the wind blows from the short base of the "L" up the long arm; the pilot lands at the tip of the long arm, and runs along it towards the short base.

JUDGING THE WIND IN FORCED LANDINGS

Quite the most difficult part of a forced landing at night is to gauge the direction of the wind. Perhaps the surest method is to loose a parachute flare, and to watch its drift. Another method is to gauge the apparent speed at which the machine passes along a line of ground lights. The latter is not very difficult if the wind is strong, and the engine is available to make comparative tests in two or more directions. Unfortunately, none of the above methods are very helpful in a gentle breeze.

CHAPTER XIV

THE RULES OF THE AERODROME AND OF THE AIR

EVERY aerodrome possesses its own code of rules, which must be mastered and obeyed by all who frequent it: some of them are actually more important than the rule of the air. Even under service conditions the rules of individual aerodromes vary, as the commander of the squadron or station is a little king in his own dominions, and retains a certain liberty to impose his own ideas. When civilian flying schools spring up like mushrooms, the rules at different aerodromes will develop considerable variety, and flying pupils, mechanics, etc., will find that they are very sharply reprimanded or punished for accidental breaches due to genuine ignorance. The plain fact is that stern discipline is essential on all flying grounds. It can never be dispensed with in the workshops, for a small piece of carelessness may involve the loss of lives. It is necessary on the turf of the aerodrome itself, as a revolving propeller is practically invisible, and may decapitate the unwary, whilst collisions between a machine which is alighting and another which is taking off may have most serious consequences. Practically every "ground rule" is important, and has sturdy common sense behind it. An underling cannot be trusted to decide when the weather is fit for a novice under training to make an ascent, whether a certain school bus is in fit condition for flight, or whether a certain pupil is sufficiently expert to take up a type of machine which he has never flown before. Finally, visiting pilots of experience must conform strictly to any local rules. For example, the rule of most aerodromes is that circuits may only be made clockwise or anti-clockwise—a regulation obviously framed to prevent collisions. At other grounds there are special rules about landing or taking off, some of which are simply designed to obtain uniformity of practice amongst pilots, whilst others meet special dangers due to peculiar local conditions. The

new-comer may resent certain reminiscences of Prussianism in the atmosphere of a well-managed aerodrome, but he will realise that death is never very far distant in possibility, if not in fact, and that such rules are enforced for the good of all concerned. They are doubly necessary because the average pilot is rather distinguished for lightsomeness of heart and general daring than for self-restraint or caution, and a crowd of young pilots require a firm hand. Under peace conditions most aerodromes will be commercial concerns. If such an aerodrome acquires an unenviable reputation as a place where accidents are frequent, its future will be imperilled.

Similar considerations must be borne in mind by the ground employés, who will find that the shops do not remind them of the happy-go-lucky system on which many a slovenly garage was run in pre-war days. In all aviation work an apparently tiny mistake assumes the dimensions of a crime, because it may be nothing more or less than camouflaged murder. The mechanic who considers that "I forgot" or "I didn't know" is a sound excuse should confine his ambitions to a cycle repair shop. Aeroplane work demands the highest efficiency and the most scrupulous conscientiousness from all concerned, for a pilot is not a motorist; he cannot get out of his cockpit at 10,000 feet and repair a minor mishap. If a wheel drops off his undercarriage or binds on its axle, he may pay for somebody else's blunder with his health or with his life.

So far as pilots are concerned, the ground rules of most aerodromes are fairly simple. The pilot must not fly without orders. He must not fly any machine but the one which is allotted to him. He must not fly the allotted machine until the responsible engineer has passed it as fit for flight. In spite of this, he should not accept the assurance of the engineer in charge, but should personally "vet" the machine to the best of his ability. In starting up his engine, he must scrupulously carry out the recognised formulæ. Before commencing the run up to take off, he must personally ascertain that none of his assistants are in dangerous positions, that the ground required for his take-off is clear, and that nobody else is about to land or take off within a considerable distance.

After taking off, he must carefully observe all local rules for low flying in the vicinity of the aerodrome. These will probably consist of a stipulation as to whether his initial cir-

cuits, as he gains height, are to be in a right or left hand direction. Possibly pilots are instructed to avoid flying over certain neighbouring buildings, e.g. hospitals. If other machines are up, he will observe the standard rules of the air, which are as follows :—

1. Two aircraft, meeting end on, and thus running the risk of a collision, must always steer to the RIGHT, and pass at a minimum distance of at least 100 metres measured between their nearest adjacent points. (A metre is approximately 39 inches.)

2. Any aircraft overtaking another aircraft is responsible for keeping clear, and must not approach within 100 metres on the right or 300 metres on the left of the overtaken craft, and must not pass directly underneath or over such overtaken aircraft. Neither must the overtaking aircraft turn in across the bows of the other aircraft after passing it.

3. When two aircraft meet at an angle, the pilot who sees the other machine on his RIGHT is responsible for keeping clear.

4. In the case of airships, a minimum clearance of 500 metres must be given.

The above rules will doubtless be superseded by a more complex code before the world is much older. The most casual perusal suggests that the above code was framed before stunt-flying developed, and the safety distances mentioned are ridiculously inadequate now that flight extends to vertical banks, speeds of 150 m.p.h., loops and other acrobatics. A revised code may not appear until international action again becomes possible. In the meantime, the four rules quoted above contain the kernel of what is necessary, for they settle that aeroplanes keep clear of each other, meet each other on the left, and observe additional precautions in overtaking. Generally speaking, pilots will be wise to give each other the widest possible berth, especially when there is a chance that the other pilot is unaware that another machine is near him.

Over and above these official rules, various unwritten laws merit universal obedience. Flying at low altitudes is dangerous to the pilot and a nuisance to the public. The merry youth who goes "hedge-hopping" may frighten a horse into bolting, or kill some timid person with a weak heart action. Stunting

over towns has resulted in a long catalogue of accidents, most of them fatal.

In the not distant future, various levels in the air will be set apart for divers types of flying machines.

Night flying in particular demands absolute obedience to local rules, especially as regards taking off and landing, and in showing the proper navigation lamps.

CHAPTER XV

FLYING OVER WATER

It is probable that in the near future long distance flights over great expanses of water will become quite common. The three main differences between land journeys and oversea flights are concerned with landing, altitude and navigation.

As regards landing, water is a very great deal harder than it looks, and it is by no means a desirable medium on which to "land" a machine with a wheel type of undercarriage, as must occasionally be done after an involuntary descent. Moreover, it is of the first importance that the "landing" should cause the minimum of injury to the machine, as an undamaged plane will support the pilot for a longer period than if the wings were seriously buckled. No oversea or cross-channel flights should be made without the aid of a wireless installation, unless the width of the channel and the altitude of flight permit a glide to shore from any point of the crossing. If a descent on the water is inevitable, the "landing" MUST be of the "pancake" type, i.e. the pilot must flatten out and take forward speed off the machine, so as to drop practically vertically into the water. If the machine strikes the water at such an acute angle as constitutes a good landing on turf, the undercarriage will be "chocked" by the resistance of the water, and the machine will cartwheel over on to its back. This possibility raises the further question of when the safety belt should be released. If it is freed before striking the water, a heavy landing may throw the pilot clean out of his cockpit, and cause him to be entangled in the wires. If he delays releasing the catch till after landing, he may be trapped under his inverted machine. The situation is dangerous in every conceivable aspect. Probably the wisest plan is to study the problem in relation to the construction of the machine in use.

Altitude is an almost perfect insurance in flights across

narrow channels. If the machine's natural gliding angle with the engine off is 1 in 7, a waterway fourteen miles wide can be crossed at a height of approximately one mile, or just over 5000 feet. If the engine stops at mid-distance, the gliding angle will permit of a landing upon terra firma at either side of the channel. If the channel is twenty-eight miles wide, the safe altitude for crossing is about 11,000 feet, and so on. Of course a channel fifty-six miles wide would not be crossed at a height of 22,000 feet, ten thousand feet being about the limit to which this principle would be applied. On long oversea flights a wireless "sending" outfit and a "flying boat" type of machine are essentials to real safety.

Navigation of a high order is absolutely requisite for prolonged flights over water. So long as navigation is visual, this factor considerably limits the weather in which such flights can be attempted. If a pilot steers by the ground, he must rely upon continued vision of the ground. In a flight across the English Channel the English and French coasts are not simultaneously visible from 10,000 feet on more than 150 days in each year. On longer crossings the possibilities of visual navigation are proportionately reduced. Directional wireless may eventually be developed for assisting oversea flights. It is said that the Zeppelins employed this system in their raids upon England, but their navigation did not suggest that accuracy could even be approached. Generally speaking, the pilot who intends to cross a waterway should calculate his compass course as closely as possible before leaving the ground, and check it by a steady flight between two ground landmarks, forming a long base, before he crosses the coast. Fixed points for setting a course or taking a bearing can be secured far out at sea by dropping slow-burning flares which ignite on touching water. This science is as yet in its infancy.

Food, hot drinks in a thermos flask, warm clothing, a life-belt, and some form of day and night signal (preferably wireless), form part of every "oversea" pilot's equipment.

The handling of seaplanes and flying boats is an art in itself, and will not be dealt with here, as it represents a "post-graduate" course for the seasoned land pilot.

APPENDIX

ABOUT AERO ENGINES

A COMPANION volume to this work (*Aeroplanes and Aero Engines*) should be consulted for an elementary account of the working of a petrol engine, and for a fuller discussion of the various types. The present Appendix is merely an introduction to aero engines, designed for the information of readers who are only familiar with the types of petrol engine used on motor-cars and motor-cycles.

Up to date all aeroplanes are propelled by petrol engines, and these engines are all of the four-stroke pattern. They differ from road engines in several important particulars, viz:

1. Range of speed.
2. Weight in proportion to power.
3. Arrangement of cylinders.
4. Cooling.
5. Provision of a thrust bearing.
6. Absence of a silencer.
7. Suitability to work in atmospheres of reduced density.

Each of these points deserves separate treatment.

1. *Range of Speed.*

A motor-car engine is designed to propel a car along the road at speeds ranging from one to perhaps seventy miles an hour. An aeroplane will not support itself in the air at less than 50 m.p.h., and may have a maximum air speed of 80 m.p.h. (Some fighting scouts can touch 140 m.p.h.) Consequently a road engine has to be flexible, whereas an aero engine does practically all its work at a fixed speed, and never runs slowly except when it is being warmed up and tested prior to a flight, or when it is throttled down for a descent. An aero engine could dispense with all speeds below, say, 1500 r.p.m. in the air; but if 1500 r.p.m. were its absolute minimum, the machine would be difficult to hold during ground tests, and the resultant vibration would be very injurious to its light structure. Most aero engines are therefore designed to tick over at about 350 r.p.m. when required; but provided the acceleration is not too rough, their behaviour at less than, say, 1400 r.p.m. is a matter of small concern. On the other hand,

no aero engine has as high a maximum speed as a car engine. The power developed by a petrol engine is closely connected with the speed at which it runs; if 100 h.p. is required for a given purpose, it is better to have a small engine which can be run up to 3000 r.p.m. than a big engine with a maximum speed of 1500 r.p.m. Unfortunately there are limits to the adoption of this principle in aeroplanes, because, for example, propellers lose their grip on the air if they are run up to very great speeds. At the present moment propellers are not run faster than about 1700 r.p.m. It follows that if the propeller is mounted direct on the engine shaft, 1700 r.p.m. is also the maximum speed for the engine; if a faster running engine is desired, the propeller must be slowed down by interposing a reduction gear between it and the engine. These gears are very heavy. On the whole, then, whereas the engine of a sporting motor-car may have a speed range varying from 150 to 3500 r.p.m., an aero engine will not run at less than 350 r.p.m., or at more than 1700 r.p.m. unless it is geared down. To phrase another aspect of the case, if an engine is accelerated from 1500 r.p.m. to 1750 r.p.m. the loads on some of the bearings may be *doubled*, thus, an engine which would be reliable at 1500 r.p.m. might demand vastly greater bearing surfaces, appreciable additions of weight and a re-designed lubrication surface before it could safely be run for three minutes at 1750 r.p.m. Since the propeller sets a limit to the r.p.m., the designer is content to calculate for plenty of power, great reliability, and low weight at a moderate running speed.

2. *Weight in proportion to Power.*

A good 1914 motor-cycle engine of 5 (actual) h.p. weighed 50 lbs. A first-rate modern aero engine of 400 h.p. need not weigh more than 800 lbs., and it is possible that some of the belligerents are developing lighter engines still; at any rate, these figures show that a motor-cycle engine scales 10 lbs. per h.p. as against the 2 lbs. per h.p. of an aero engine. The weight of the engine is a vital element in the design of an aeroplane. It cannot be asserted that wings of a given area will support a given weight, as the shape of the wings and other factors affect the lift obtainable from a surface. But when an engineer is designing an aeroplane, he reaches a point at which he can say "It will take 500 h.p. to drive this machine, and the weight must not exceed 2 tons, considering the purpose I have in view, and the speed and climb essential to my purpose." The 2 tons include the engine; the more weight he allots to the engine, the less is available for crew and cargo; consequently, whether his aeroplane is to carry bombs or mails, he wants the engine to be as light as is consistent with reliability. The weight of engines has been cut

down extraordinarily during the war, partly by the use of light metals, partly by brilliant improvements in design and in machining of parts, partly by utilising air cooling. In 1914 many aero engines weighed 8 lbs. per h.p. without oil, water, fuel, or tanks; nowadays a first-class engine will weigh between 2 and 3 lbs. "dry." After the war slight concessions will doubtless be made to reliability and durability, but progress in weight-saving will continue, and 2 lbs. per h.p. will not remain as a minimum limit.

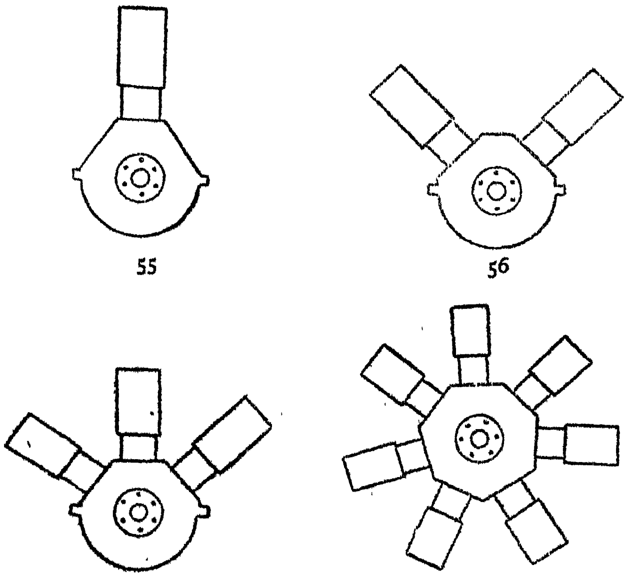
3. *Arrangement of Cylinders.*

The high-powered motor-car engine is usually of the vertical six-cylinder type, which would be very popular in the air if 100 h.p. were sufficient for an aeroplane. When an aeroplane requires 300 h.p., as 1918 fighting single-seated scouts did, or 1500 h.p., like the giant German bombers, a vertical six-cylinder engine is less suitable. A "big six" is very high, and awkward to house in a nicely stream-lined fuselage, whilst it occupies precious space in the front end, where the crew have to be accommodated. Its long crank-shaft and crank-case are very heavy, and an engine of this type will weigh a good deal more than 2 lbs. per h.p. Its leviathan impulses will rack the structure of the machine considerably. If we divide the 300 h.p. say between 12 cylinders mounted V-wise on one crank-case, we shall get a lower, shorter, lighter, and smoother engine, with no compensating disadvantages of any kind. Thus the V-engine is ousting the six-cylinder for high powers, and many manufacturers are experimenting with three rows of cylinders resembling a "broad arrow" when seen end on.

It is also obvious that the huge crank-shaft and crank-case can be vastly reduced in weight and length if the desired horse-power is divided between cylinders arranged star-wise round a shallow circular crank-case; and this is actually done on such famous "radial" engines as the French Canton-Unné, the A.B.C. "Dragon-fly," and in all the "rotary" engines.

Air cooling offers a short cut to weight reductions, as tanks, radiators, piping, pumps, jackets and water are all heavy. Up to date the rotary type of engine, described in more detail on p. 152, is the best known air-cooled engine for flying purposes. It has a stationary crank-case, round which the crank-case and cylinders revolve, the propeller being fixed to the crank-case. Unfortunately its rotation creates an appreciable wind resistance, absorbing perhaps one-eighth of the total gross horse-power; furthermore, its carburation and lubrication are so crude that it wastes a great deal of fuel and oil. If such an engine is used for prolonged flights, the weight of its big tanks counterbalances the low "dry" weight. Rotary engines enjoyed a great vogue in the war,

because their cooling was not affected by bullet-holes, because their concentration of weight made the aeroplane easy to manœuvre, because they took up so little space in the fuselage, and because on short flights with small tanks they touched the minimum weight per horse-power. After the war we shall hear less about them. The air-cooled radial is already supplanting them.



55 56 57 58

FIGS. 55–58.—Silhouettes of leading types of aero engine.

55. Vertical. 56. Vee. 57. Broad arrow. 58. Radial and rotary.

4. *Cooling.*

The benefits of air cooling have been indicated in the previous paragraph. On the road the temperature and the strength of the wind remain tolerably constant throughout a run. In the air, the temperature may be 100 degrees just after taking off, and may sink to freezing-point during a climb. Again, a motor-car varies its speed between 20 and 40 miles an hour during a trip on the road; but an aeroplane may have a speed range of from 50 to 150 miles an hour. In other words, the aero engine has to face acute extremes of draught and temperature. These extremes

create trouble even with water cooling; the usual system is to use a pump which circulates the cooling water at a great rate, and to fit a radiator which will just prevent the water from boiling at the greatest temperatures and weakest draughts likely to be encountered. Such a system will grossly overheat its engine when it is flying slowly at arctic heights. Consequently, the radiator is fitted with a blind or shutter, adjustable by a lever in the cockpit; and the cooling is varied to suit the conditions of flight. Similar troubles arise with air cooling. Prior to the war no engineers in this country relied on air cooling for engines of more than 8 h.p. Nowadays enormous engines are kept cool without the aid of water, in spite of the fact that flight may direct a blast of icy air travelling at 150 m.p.h. upon the front of the cylinders, whilst the rear of the cylinders is practically shielded. To sum up the progress, it is now understood that *sheer heat* is

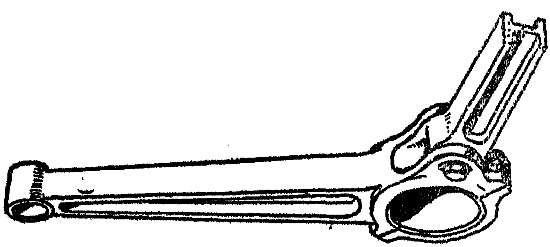


FIG. 59.—Articulated type of connecting-rod used on Vee engines.

not the real enemy, but that the alleged defects of air cooling are more connected with *uneven heating*, leading to the excessive expansion of the hotter parts, and consequent friction or loss of compression.

5. *Thrust Bearing.*

Before an air-screw can push or pull an aeroplane through the atmosphere, it must lay hold of some part of the aeroplane. As the propeller shaft is spinning round while it does its work, great friction will arise at the point where the rotating shaft is connected to the non-rotating aeroplane. This is taken up by a ball-thrust bearing, which is usually designed to take thrust in either direction, so that the engine may be fitted to either a pusher or a tractor machine.

6. *Absence of Silencers.*

During the war little or no effort was made to relieve the pilot of the intolerable uproar of the exhaust. The weight, wind-

resistance and back-pressure implied by fitting silencers were serious factors. When commercial passenger-carrying aeroplanes are developed, these points will require attention.

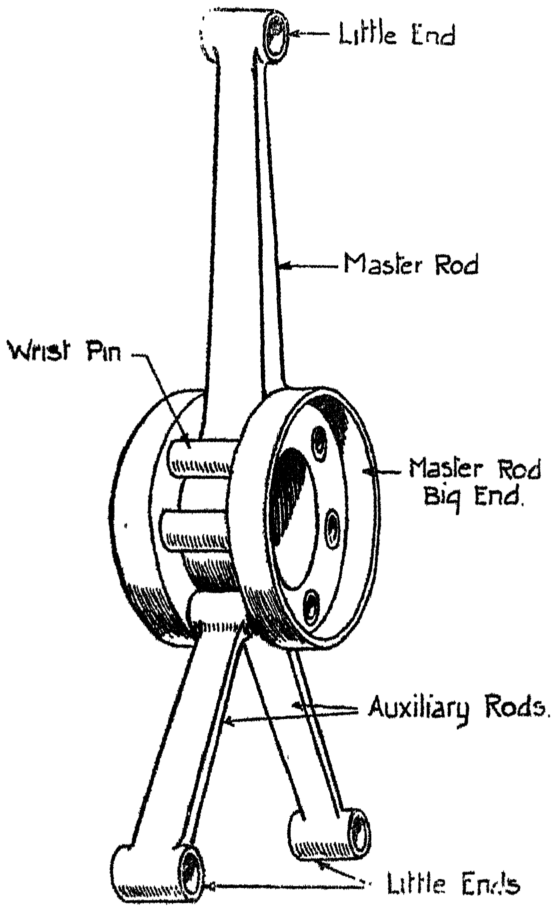


FIG. 60.—The "master rod" system of arranging the connecting-rods on radial and rotary engines.

7. *Suitability for High Altitude Work.*

The density of the air becomes gradually less as an aeroplane gains altitude. This fact affects flight in several respects. It

affects the engine more particularly by upsetting the "mixture," as the gas compounded of petrol vapour and air is usually termed. At 20,000 feet the air contains much less oxygen than at ground level, and is also much less compressed. Correction for altitude is as yet in its infancy. A common method consists of reducing the petrol supply to compensate for the weakness of the air.

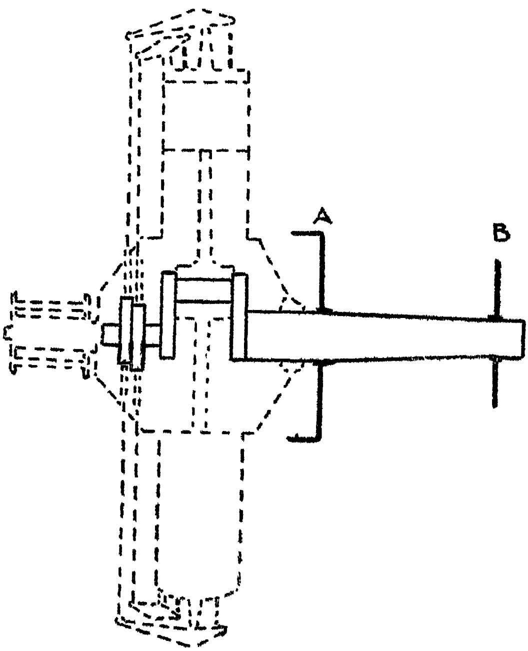


FIG. 61.—Diagram of a rotary engine.

The dotted lines indicate the rotating parts, the solid lines show the stationary portions.

A and B are the two engine supports, which are bolted to ring plates in the fuselage of the aeroplane.

Some engines are also designed with a special view to high altitude flight. They compress their charges of gas very heavily, and consequently must never be run on full throttle near the ground; on reaching great heights they are allowed to inhale a full charge, and compress it very heavily.

VARIOUS TYPES OF ENGINE

Of the four leading types—the vertical, the Vee, the rotary and the radial—the first two are familiar to all motorists, and need no description here. Silhouettes are given on page 147. The method

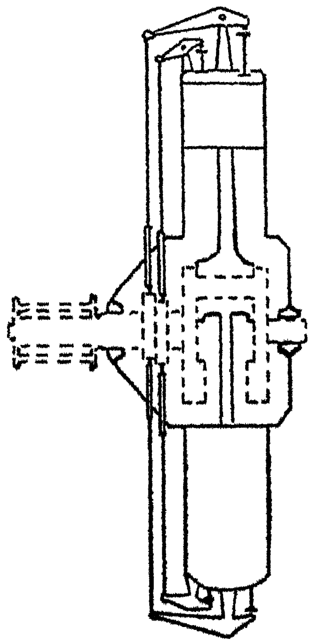


FIG. 62.—Diagram of a radial engine.

Compare this with Fig. 61. The dotted lines show the rotating parts, the solid lines the non-rotating parts.

of mounting the connecting-rods of a Vee engine on the crankshaft perhaps requires a word of explanation. The big ends of the rods on one side of the engine may work on the crank-pins in the ordinary way; the outer sides of these big ends will be covered with bearing metal, on which the forked ends of the opposite rods oscillate. Alternatively, the main connecting-rods may have lugs machined on them, in which "wrist-pins" are mounted; the auxiliary connecting-rods will work on these wrist-pins. On a "broad arrow" engine the connecting-rods of both

side "banks" of cylinders may work on wrist-pins mounted on the master or central connecting-rods, as described above.

The connecting-rod assembly of a radial or rotary engine is illustrated in Fig. 60. This unit will ride on enormous ball or roller bearings mounted on the single crank-pin or "throw" of the crank-shaft. The crank-shaft will be made in two pieces for convenience in mounting or dismounting the connecting-rods; the joint will be in the "throw," and will consist of a taper, key, and substantial locking devices.

The lubrication of a radial engine presents no difficulty; the oil need only be introduced into the hollow crank-shaft and provided with exits at suitable places, when centrifugal force will distribute it. Oil will not drain down into the lower cylinders, as the spinning crank and rods will catch it before gravity can act. The valves will be operated by an arrangement resembling the back gear of a lathe. Pumps and magnetos may be mounted on the back plate, and their pinions will be driven by a gear mounted on the crank-shaft. Radial and rotary engines always possess an uneven number of cylinders, unless a double-throw crankshaft is employed. The reason for this is that even firing intervals must be provided in the interests of smooth running, especially as no flywheel is used. For example, an eight-cylinder radial engine on the four-stroke principle cannot possibly fire evenly, seeing that each cylinder fires once in two revolutions; if the firing order were 1, 2, 3, 4, 5, 6, 7, 8, all the cylinders would fire on the first revolution, and none on the second; the engine would jerk itself to bits in a minute. If the order were 1, 3, 5, 7 . . . the firing intervals would be even up to this point (viz. 90 degrees, as eight cylinders, disposed round a circle (360 degrees), would be 45 degrees apart); but which cylinder is to fire fifth? Cylinder No. 1 is the correct distance from No. 7, which has just fired, i.e. 45 degrees; but No. 1 cylinder cannot fire now, for it is on its inlet stroke; if No. 8 fires next, it is only 45 degrees past No. 7, and the firing intervals would run 90, 90, 90, 90, 45 . . . degrees, which imply terrific vibration. Consequently such engines have 7, 9, or 11 cylinders; all the odd numbers fire first, and then all the even numbers, which permits of equal firing intervals throughout.

The rotary engine resembles the radial in silhouette, but its crank-shaft is stationary, and is keyed and locked into two circular support plates of steel bolted into the fuselage of the aeroplane. Fig. 61 gives a side section of such an engine. A is the main support in the fuselage, and B the rear support. The dotted lines indicate the rotating parts of the engine, whilst the complete lines show the stationary parts, viz. the crank-shaft and the supports. Fig. 62 shows by contrast a radial engine

with its rotating crank-shaft in dotted line. Fig. 63 is a diagram showing why the mass of a rotary engine revolves round the crank-shaft. The cylinder at the top of the diagram is in the position at which all the cylinders fire. An explosion has just taken place above its piston. The exploding gas must have room to expand. The cylinder cannot fly off to make the necessary room, for it is firmly bolted to the crank-case. The piston cannot slide vertically downwards, because it is attached by a rigid connecting-rod to the immovable crank-pin. The same cylinder is sketched in again lower down on

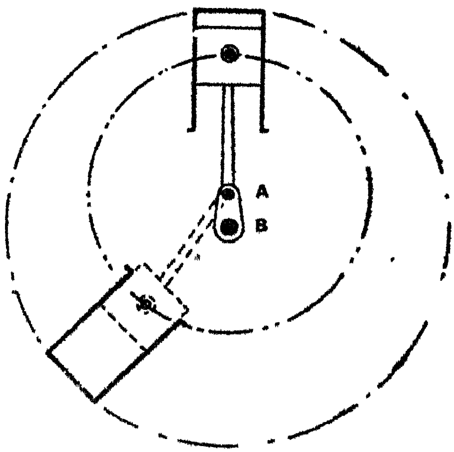


FIG. 63.—Diagram explaining why the cylinders of a rotary engine revolve.

the left of the diagram. Notice that as the cylinder swings down to its new position, *the space between the top of the piston and the cylinder head has mysteriously increased in area.* The explanation of this apparent miracle is quite simple. It is true that both the piston and the cylinder swing round anti-clockwise to the left, but *they swing round different centres.* The pistons swing round the crank-pin centre at A, which is several inches above the crank-shaft centre at B. Consequently the pistons follow the path of the smaller circle, and the cylinders follow the path of the large outer circle.

Needless to say, the rotating parts of the engine swing on ball-bearings mounted on the crank-shaft.

The carburation is peculiar, as the carburettor is bolted to the tail-end of the hollow crank-shaft, and the gas is drawn up the

inside of the crank-shaft by crank-case suction. The path by which the mixture reaches the combustion chambers varies on different makes of engine. It may go through a suction-operated valve in the crown of each piston, or it may pass into a "gas-box" at the rear of the crank-case, from which induction pipes distribute it to each cylinder head in turn.

The exhaust gases pass direct into the air, or rather into the cowling over the engine.

Oil is usually pumped into the hollow crank-shaft, discharged through small holes, and distributed by centrifugal force. The consumption is excessive, as the lubricant cannot be circulated over and over again; centrifugal force slings it up into the cylinder heads, and it is either burnt or blown out with the exhaust gas.

Rotary engines are heavier than radial engines of the same size, as the crank-case and cylinders have to withstand centrifugal forces as well as the usual explosive stresses, and must therefore be built with additional strength.

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